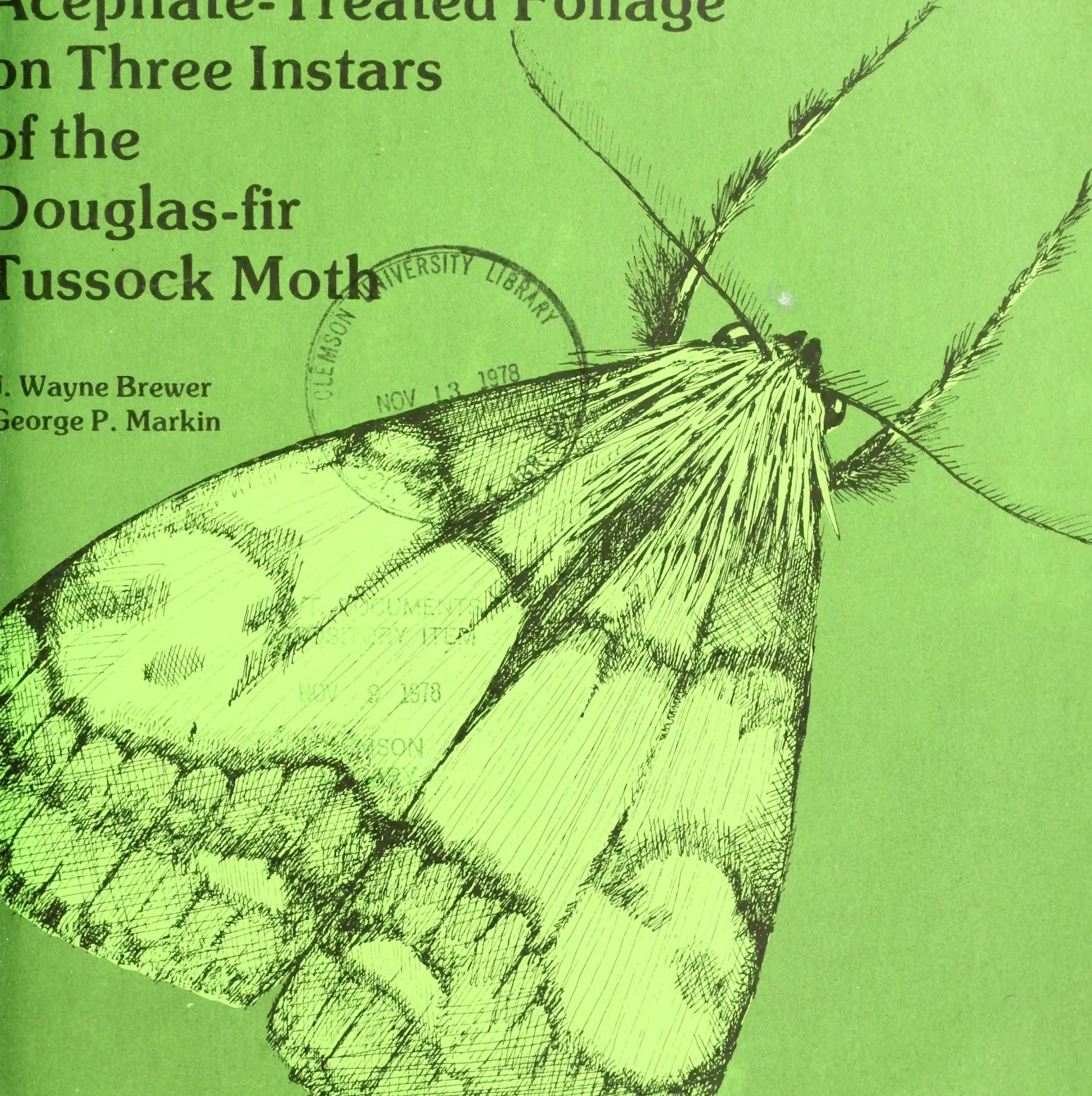
Digitized by the Internet Archive
in 2013

http://archive.org/details/researchpaper24paci

1978
USDA Forest Service Research Paper PNW-241

Bioassay of Acephate-Treated Foliage on Three Instars of the Douglas-fir Tussock Moth

J. Wayne Brewer
George P. Markin



CLEMSON UNIVERSITY LIBRARY
NOV 13 1978

T. DOCUMENTS
SITORY ITEM
NOV 9 1978
CLEMSON
LIBRARY

cific Northwest Forest and Range Experiment Station
S. Department of Agriculture
Forest Service
Portland, Oregon

usda douglas-fir tussock moth • research & development program •

THE AUTHORS

J. WAYNE BREWER is with the Department of Zoology and Entomology, Colorado State University, Fort Collins, Colorado.

GEORGE P. MARKIN is with the USDA Forest Service, Methods Application Group, Davis, California.

The research reported here was financed in whole or part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

BIOASSAY OF ACEPHATE-TREATED FOLIAGE ON THREE INSTARS OF THE DOUGLAS-FIR TUSSOCK MOTH

Reference Abstract

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata.*

BOUND BY THE NATIONAL LIBRARY BINDERY CO. OF GA.

RESEARCH SUMMARY

Research Paper PNW-241

1978

Field application of acephate was made on a series of 16-acre (6.5 ha) plots of Douglas-fir *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., at the rate of 1 lb AI/acre (1.12 kg/ha) in central Washington. Bioassays of first, second, and third instars of *Orgyia pseudotsugata* (McDunnough) on foliage from treated and check plots indicated that acephate caused a significant increase in larval mortality. The highest mortality, 88 percent, occurred in first instars tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. Mortality trends were similar for the three instars over the 21-day post-treatment sampling period.

Contents

Page

INTRODUCTION 1

MATERIALS AND METHODS 1
  Experimental Design 1
  Application 1
  Evaluation 2
  Bioassay Samples 2
  Bioassay 2
  Statistical Analysis 3

RESULTS AND DISCUSSION 3
  Deposit Assessment 3
  Efficacy-Deposit 3
  Efficacy-Time 4
  Efficacy-Instars 5
  Time-Instar Interaction 5
  General Comments 6

LITERATURE CITED 6

Introduction

Acephate is an organophosphate insecticide with systemic activity (Werner 1974) and low mammalian toxicity. It appears to be effective against a variety of forest pests and yet seems more compatible with environmental concerns than many other chemical insecticides (Brewer and O'Neal 1977). Acephate has been field tested against gypsy moth, *Lymantria dispar* (L.), elm spanworm, *Ennomos subsignarius* (Hubner) Doane and Dunbar (1973), elm leaf beetle, *Pyrrhalta luteola* (Muller) Brewer (1973), eastern spruce budworm, *Choristoneura fumiferana* (Clemens) Hopewell and Nigam (1974) and a looper *Lambdina athasaria athasaria* (Walker) Cameron and Mastro (1975). Neisess et al. (1976) demonstrated that acephate gave good control of second, and third instars of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough)[1] in small plots. We wanted to determine if field application of acephate would cause different levels of mortality of the first three instars of the Douglas-fir tussock moth. We also wanted to study the residual effect of acephate on these instars. We used laboratory bioassays of field-treated foliage in the test because we could better control developmental stage of test larvae than under field conditions. Also, this approach allowed us to determine the residual activity on larvae introduced at specified time intervals after treatment but still incorporated the normal effects of chemical weathering that occur in the field.

Materials and Methods

The study was conducted within the framework of a large aerial application test of various types of insecticides located ca. 25 miles (40 km) northeast of Ellensburg, (Kititas Co.) Wash., in the Swauk Creek Drainage of the Wenatchee National Forest. The treatments in this study were acephate 75 percent SP and an unsprayed check. The dosage was 1 lb AI (1.12 kg) in 1 gal (3.8 liter) H_2O with 3.785 g of fluorescent dye (Rhodamine B Extra S (GAF))[2] added for deposit assessment. The material was applied at the rate of 1 gal/acre (3.8 liter/ha).

EXPERIMENTAL DESIGN

Six plots, 16 acres (6.5 ha) each, were established with each plot containing a 15-tree cluster designated for sampling and spray deposit analysis. The plots were separated by a minimum of 1 kilometer. Sample trees were either open-grown Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, or grand fir, *Abies grandis* (Dougl.) Lindl., 30 to 50 ft (9 to 15 m) in height. Plot corners and boundaries were marked with brilliantly colored plastic markers 18 X 60 in (45.7 X 152.4 cm) pulled into treetops with line shot over the trees with a crossbow or a line-throwing gun (Maksymiuk 1975). In some cases, plot corners were designated by markers dropped from a helicopter.

Three replicates of each of two treatments were used, with plots assigned at random. Check plots were not sprayed nor were corners marked, but sample trees were designated.

APPLICATION

The acephate formulation was applied to the three treated plots by a Hiller UH-12E helicopter equipped with eight spinning-disk atomizers mounted on an 18-ft (5.5-m) support bracket. The atomizers were a modified version of the Balls Turbear spinning nozzle (Boving et al. 1971) consisting of 12 plates, 4 inches in diameter (10 cm), driven by an electric motor at 9000 rpm. The atomizers were fed from two interconnected 10-gal (37.8-liter) stainless steel tanks pressurized at 40 lb/in^2 (2.8 kg/cm^2) by compressed nitrogen. The aircraft treated one 16-acre (6.47-ha) plot/flight with a reserve of 4 gal (15.1 liter) of material remaining in the system.

---

[1] Lepidoptera: Lymantriidae.

[2] General Aniline & Film Corp.

Applications were made during the early morning of June 15. During applications, the temperature ranged from 44° to 52°F (6.6° to 11°C) and the RH from 85 to 100 percent. There was no measurable wind at plot one and less than 0.5 mph (0.8 km/h) at the other two sprayed plots. There was no measurable precipitation on the plots until a brief rain shower occurred on June 18 and again on June 19. There was no further precipitation during the sampling period.

During the operation, the pilot oriented himself over the plot using the four treetop corner markers and directions from a radio-equipped ground observer. Spraying started on the downwind side of the plot and progressed upwind with swaths spaced 50 ft (15 m) apart at 35-50 ft (11-15 m) above the treetops.

EVALUATION

Spray Deposit Assessment.--Spray deposit was sampled at the forest floor of sprayed plots with 6 in square (15.2-cm) aluminum plates and 4 X 5 in (10.2 X 12.7 cm) white Kromekote cards according to the procedure of Maksymiuk and Orchard (1975). Two plates and one card were placed in small openings adjacent to each sample tree. Foliage samples for deposit analysis were collected from sample trees within 3 hours of spraying. One 15-in (38.1-cm) branch sample was cut from each of four cardinal directions from midcrown. Plates, cards, and foliage were transported to the laboratory for analysis.

Amounts of spray deposit on the foliage and aluminum plates were determined by a modification of the fluorometric analysis reported by Yates and Akesson (1963), using a Turner Model #430 Spectrofluorometer. For foliage samples, 5 g subsamples of air-dried foliage were taken at random from each branch sample. Spray deposit was eluted from needles by washing them 20 min in 50 ml of H_2O with the addition of 3 drops of Laboratory Aerosol (10 percent AI dioctyl solium sulfosucciinate). Deposit was eluted from aluminum plates with another 10 ml of the aforementioned solution. Deposit from the plates was converted to gal per acre and from foliage to ml of formulation per g of air-dried foliage.

Atomization and drop densities of the spray deposit on the Kromekote cards were determined with a Quantimet 720 Image Analyzer.

BIOASSAY SAMPLES

A large foliage sample ca. 36 in (90 cm) in length was removed from each of four sides of each of the 15 designated sample trees for all three replications of the treatments 1 day prior to insecticide application and at 1, 7, 14, and 21 days post-treatment. Each of the three composite subsamples for use in the larval bioassay was made by taking one 12-, to 15-in (30-, to 40-cm) branchlet from each of the four large foliage samples. Each composite subsample was placed in an 18 X 6 in (45 X 15 cm) perforated plastic bag. Foliage was stripped from the basal 4 to 6 in (10 to 15 cm) of the branches and the bag sealed at the base of the foliage so that the stripped branches protruded. The branch ends were placed in water-filled vials to reduce desiccation.

BIOASSAY

At the laboratory, 20 and later 10 Douglas-fir tussock moth larvae of first, second or third instar, as appropriate, were introduced into the plastic bag containing the foliage samples. At the end of 7 days, mortality was determined for that particular sample.

Larvae were introduced into the sample bags as soon as possible, usually on the day following collection. Foliage samples were stored temporarily in a cold room at 40°F (4.5°C) prior to introduction of the larvae. Because of lack of suitable larvae, it was frequently necessary to store foliage in the cold room for up to 23 days prior to introduction of the larvae (table 1), which undoubtedly altered insecticide potency and larval survival rates.

STATISTICAL ANALYSIS

Mortality data were subjected to analyses of variance, covariance, and regression. Adjustment of the mortality data from the various treatments was performed using an analysis of covariance with the pretreatment counts as the covariant which allowed the results to be compared directly. Thus data on pretreatment mortality are not presented. Differences were considered significant at the 0.05 probability level.

Results and Discussion

DEPOSIT ASSESSMENT

Spray coverage varied considerably among the three treated plots (table 2). Mean deposits ranged from 0.130 to 0.599 gal/acre. Substantial variation also occurred in spray droplet numbers with a range of 16.2 to 39.4 drops/cm^2. Deposit trends from foliage samples were similar to those from aluminum plates at ground level. In general, droplet size (VMD) varied inversely with ml per g of spray from foliage and gal/acre as determined from aluminum plates.

EFFICACY - DEPOSIT

Mean larval mortality (unadjusted) shows that mortality was highest in plots that received the highest deposits as measured in gal per acre and drops per cm^2, and lower where less material was deposited (table 1). Thus, it appears

Table 1--*Mean percent larval mortality by plot with gal per acre of acephate at ground level as determined from aluminum plate samples.*[1] *Kititas County, Washington, 1975*

Plot	Time after treatment (days)[2]					
	gal/ acre	-1[3]	1	7	14	21
Foliage storage[2] time (days)		0	7	23	21	21
Treated						
Plot I Liberty Rd. 2	0.218	6.6	70.3	30.6	20.6	18.0
Plot II Mill Creek 2	.130	3.7	69.0	21.0	11.0	21.3
Plot III Iron Creek 3	.599	10.0	95.3	27.3	23.0	24.0
Mean	.316	6.8	78.2	26.3	18.2	21.1
Check						
Plot I Iron Creek 2	--	8.3	9.7	8.7	13.3	14.7
Plot II Mill Creek	--	6.3	4.7	9.0	13.3	13.7
Plot III Blue Creek	--	7.3	9.0	6.0	7.7	10.0
Mean	--	7.3	7.8	7.9	11.4	12.8

[1] Data from 3 larval instars are combined.

[2] Lack of suitable larvae made it necessary to store foliage at 40°F prior to larval introduction.

[3] Day -1 counts were made 1 day prior to insecticide application.

Table 2--*Acephate spray deposit recovered from sample tree foliage and from ground level plots. Kititas County, Washington, 1975*

Treatment (plot)	Spray deposit			
	ml/g foliage	Ground level		
		Grams/acre	Drops/cm^2	VMD[1] (μm)
Acephate				
I Liberty Rd. 2	0.210	0.218	16.2	205
II Mill Creek	.125	.130	17.8	222
III Iron Creek 3	.285	.599	39.4	172
Average	.207	.316	24.5	200

[1] VMD = Volume mean diameter, the drop diameter that satisfies the condition that half the spray volume is of drops larger and half is of drops smaller than the VMD.

likely that some of the variation in larval mortality was a result of variation in the amount of material reaching the plots. Mortality from two plots (Liberty Rd. 2 and Mill Creek 2) was not as high as levels reported previously by Neisess et al. (1976), for acephate on Douglas-fir tussock moth larvae. That test was not directly comparable to this one, however, because Neisess et al. (1976), applied the material directly to field populations of the tussock moth, providing contact insecticidal action on the larvae, which was not the case in our present study. Also, in our bioassay method, larvae were not introduced until 24+ h after application; so some insecticidal activity was presumably lost prior to the first larval introduction. These test differences, in addition to the low insecticide deposit levels from those two plots, probably account for the low mortality compared with that reported by Neisess et al. (1976).

EFFICACY - TIME

Adjusted mean mortality data combined for all 3 instars throughout the sampling period were 37.5 percent in bioassays of foliage from treated plots compared with 8.8 percent for untreated checks (table 3). The highest level of mortality occurred on foliage samples collected at day 1 after insecticide application when 77.2 percent of all larvae in the bioassay, regardless of instar, were killed, compared with 7.6 percent for larvae on untreated foliage. Thereafter, mortality decreased rapidly. At 7 days post-treatment, mean larval mortality from treated foliage was 28.4 percent compared with 8.1 percent for untreated material. Differences in larval mortality between treated and untreated foliage decreased further at the 14, and 21 day post-treatment sampling periods. These data indicate that, under our study conditions, larval mortality beyond 7 days after treatment was not significantly greater than would be expected under natural conditions. Rain showers that occurred on days 3 and 4 after treatment probably washed some insecticidal deposit from the foliage. Storage of foliage in the cold room (table 1) prior to larval introduction undoubtedly was a factor in the loss of insecticidal activity. The considerable residual activity, in spite of storage, suggests that effects might have lasted longer if foliage had not been stored.

It appears from the field and laboratory conditions in our study, therefore, that the residual activity of acephate is less than 14 days against the three instars of the Douglas-fir tussock moth we tested. Cameron and Mastro (1975) reported little activity of acephate on a hemlock looper in Pennsylvania after

Table 3--*Adjusted percentage mortality means*[1] *of acephate treatment vs. check for 3 instars of Douglas-fir tussock moth. Kititas County, Washington, 1975*

Treatment	Time after application (days)				
	1	7	14	21	Mean
Acephate					
1st instar	87.8	40.1	29.2	35.6	[2]48.2
2d instar	77.0	29.0	17.7	19.5	35.8
3d instar	68.1	17.4	7.4	6.7	24.9
Means[1]	77.2	28.4	17.7	20.7	37.5
Check					
1st instar	16.9	5.7	19.4	24.3	16.6
2d instar	2.3	13.6	11.5	12.6	10.0
3d instar	2.1	4.2	2.2	3.6	3.0
Means[1]	7.6	8.1	11.8	13.6	8.8

[1] Means are adjusted to account for differing mortality on pretreatment foliage samples from the various plots using this mortality as a covariant. Since various means are adjusted according to different regression lines, arithmetic means of data presented are not necessarily equal to adjusted means.

[2] Mean instar mortality without regard to time after treatment.

1 week. Nigam (1975), using a laboratory bioassay technique for acephate, reported that mortality of spruce budworm larvae dropped from 95 percent immediately after treatment to 15 percent 5 days later. Thus it would seem that application of acephate must be closely timed to coincide with insect activity because of the short residual action of the material.

EFFICACY - INSTARS

Adjusted mean larval mortality data for each of the first, second and third instars, combined for all sampling periods, were significantly different in bioassays of treated than untreated foliage (table 3). Thus, treatment with acephate against any of the three instars tested could be expected to produce significant mortality compared with check plots. The highest mean mortality level (48.2 percent) for all four sampling intervals occurred when first instars were placed on treated foliage. Thereafter, mean mortality declined to 35.8 percent for second, and 24.9 percent for third instars, compared with 16.6, 10.0, and 3.0 percent mortality for first, second, and third instars, respectively, on check foliage. The significant interaction between treatment and instar indicates that expected mortality resulting from acephate treatment decreases as the insect goes from first to second to third instar (table 3). Thus, application of acephate against first instars should produce the greatest mortality regardless of time of sampling, at least up to 21 days post-treatment.

TIME-INSTAR INTERACTION

Table 3 also presents adjusted mortality means from treated plots and untreated controls for the three instars at four time periods after treatment. The instar X time interaction was not significant indicating that the general mortality trends for the three instars were similar over the 21-day postspray sampling period.

In the acephate treated plots, the greatest change in mortality over successive time periods occurred between days 1 and 7 after treatment. In the check plots, mortality varied somewhat but was generally similar throughout the sampling period.

GENERAL COMMENTS

The results of this study demonstrate that acephate gave control of all three instars of the Douglas-fir tussock moth tested. The fact that the level of control was not as high as reported by some previous investigators may be a result of some of the limitations of using laboratory bioassays on field-treated foliage and the special problems we encountered in this particular test. However, this method does offer a valuable approach to insecticide evaluation. Most important, the investigators are not dependent on field populations of the pest insect. Residual activity of the insecticide also is easily measured, since new insect groups may be introduced at any selected time interval after treatment. In addition, counts may be made more easily, and perhaps more accurately, under laboratory conditions than in the field.

In laboratory bioassays of field-treated foliage, pretreatment tests are of considerable value. These bioassays may be used as an indicator of foliage quality, which may differ among plots, perhaps as a result of earlier or unknown insecticide applications. In addition, pretreatment bioassays may provide a baseline for determination of changes in control plots during the test, perhaps as a result of drift from treated plots. Some of the limitations of laboratory bioassays for evaluation of field applied insecticides have been previously noted, i.e., the lack of contact action on the target insect, and the loss of the initial, and possible high, mortality at the time of application. Other limitations are that the pest insect must be amenable to laboratory culture and the cost is considerable for facilities and personnel for the insect-rearing process.

Literature Cited

Boving, P. A., B. Maksymiuk, R. G. Winterfeld, and R. D. Orchard.
1971. Equipment needs for aerial application of microbial insecticides. Trans. Am. Soc. Agric. Eng. 14:48-51.

Brewer, J. W.
1973. Control of the elm leaf beetle in Colorado. J. Econ. Entomol. 66:162-64.

Brewer, J. W. and J. O'Neal.
1977. Early ground application of acephate for control of the Western Spruce budworm on Douglas-fir. Can. Entomol. 109:1153-1158.

Cameron, E. A. and V. C. Mastro.
1975. Control of a looper, *Lambdina athasaria athasaria* on hemlock with three chemical insecticides. Can. Entomol. 58:800-802.

Doane, C. C. and D. M Dunbar.
1973. Field evaluation of insecticides against the gypsy moth and elm spanworm and repellent action of clordimeform. Can. Entomol. 66:1187-9.

Hopewell, W. W., and P. C. Nigam.
1974. Field evaluation of Orthene®, phoxim and fenitrothion against spruce budworm (*Choristoneura fermiferana*), applied as simulated aerial spray. Dep. Environ. Can. For. Serv. Rep. CC-X-83. 6 p.

Maksymiuk, B.
1975. Marking methods for improving Aerial application of forest pesticides. USDA For. Serv. Res. Note PNW-262. 10 p.

Maksymiuk, B. and R. D. Orchard.
1975. Distribution of aerially applied *Bacillus thuringienses* for controlling defoliating insects in a hardwood forest. USDA For. Serv. Res. Note PNW-246, 12 p.

Neisess, John, George P. Markin, and Randy Schaefer.
1976. Field evaluations of Acephate and Dimilin against the Douglas-fir tussock moth. J. Econ. Entomol. 69:783-786.

Nigam, P. C.
1975. Strategic chemicals for protection of coniferous forests from insect pests. Chem. Control Res. Inst., Ottawa, Ontario, Inf. Rep. CC-X-92. 6 p.

Werner, R. A.
1974. Penetration and persistence of systemic insecticides in seeds and seedlings of southern pines. J. Econ. Entomol. 67:81-84.

Yates, W. E., and N. B. Akesson.
1963. Fluorescent tracers for quantitative microresidue analysis. Trans. Amer. Soc. Agric. Eng. Trans. 6:104-107, 114.

GPO 986-446

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage on three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Brewer, J. Wayne and George P. Markin.
1978. Bioassay of acephate-treated foliage or three instars of the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-241, 7 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field application of acephate was made on 16-acre plots of Douglas-fir and grand fir at 1 lb active ingredient per acre. Bioassays of first, second, and third instars of the Douglas-fir tussock moth indicated that acephate caused the highest mortality on first instar larvae tested 1 day after treatment. Mortality decreased with older instars and with time after treatment. General mortality trends were similar for the three instars.

KEYWORDS: Bioassay, acephate, insect damage control (forest), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

*Mailing address: Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
Portland, Oregon 97208*

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

USDA Forest Service Research Paper PNW-242
1978

CLEMSON UNIVERSITY LIBRARY
DEC 1 1978
SCI., TECH. & AGR. DIV.

Survival and Growth of Planted Conifers on the Dead Indian Plateau East of Ashland, Oregon

Denis M. Williamson
Don Minore

Pacific Northwest Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture
Portland, Oregon

AUTHORS

DENIS M. WILLIAMSON is a forester with the Bureau of Land Management. DON MINORE is Principal Plant Ecologist with the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon.

SURVIVAL AND GROWTH OF PLANTED CONIFERS ON THE DEAD INDIAN PLATEAU EAST OF ASHLAND, OREGON

Reference Abstract

Williamson, Denis M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Survival and growth of Douglas-fir, white fir, and ponderosa pine seedlings were studied in experimental plantations. Both bare-root and containerized seedlings were tested in the open and under partial-cut canopy. Some were caged, some watered, and some fenced. Survival of all species was much better under the partial-cut canopy than in the open, where ponderosa pine survived better than Douglas-fir or white fir. Containerized Douglas-fir and white fir seedlings grew best under the canopy. Underplanting is recommended on the Dead Indian Plateau.

KEYWORDS: Seedling survival, seedling growth, bare-root nursery stock, container nursery stock, Douglas-fir, white fir, ponderosa pine, Oregon (Dead Indian Plateau).

RESEARCH SUMMARY

Research Paper PNW-242

1978

Bare-root and containerized ponderosa pine, Douglas-fir, and white fir seedlings were planted at four severe sites on the Dead Indian Plateau. A split-split plot experimental design was used to test the influences of overstory canopy, gopher caging, cattle fencing, and irrigation on the survival and growth of these planted seedlings for two growing seasons.

The presence or absence of an overstory canopy apparently was the single most important factor in determining plantation success or failure. Survival was excellent (88.8 percent) under the partial-cut canopy, poor (36.4 percent) in the open. Ponderosa pine survival (58.6 percent) was better than either Douglas-fir (21.1-percent) or white fir (29.4-percent) survival in the open, but species survival did not differ significantly under the canopy. As caging improved survival in the open but not under the canopy, significant gopher damage apparently occurred only in the open clearcut areas.

Frost damage also was much more severe in the open clearcut areas than it was under partial-cut

canopies. Thermograph records indicated many more freezing summer nights in the open clearcuts, with minimum temperatures averaging 5°C (9°F) colder there than in adjacent partial-cut stands.

Cattle fencing noticeably increased the density and height of competing vegetation in the open cleacut areas but did not significantly affect seedling survival. Unusually wet summers probably eliminated the effect of this vegetative competition. Unusually wet weather also probably was associated with the lack of any significant irrigation effect.

Survival of the bare-root stock (65.3 percent) was better than survival of containerized seedlings (59.9 percent). Under the canopy, however, where most of the survival occurred, containerized seedlings grew significantly faster than bare-root seedlings. This superior containerized growth was particularly noticeable in the Douglas-fir and white fir stock. It was much less evident in ponderosa pine.

Our data indicate that plantations in open, clearcut areas are less likely to succeed than those established under overstory canopies on the Dead Indian Plateau; but ponderosa pine is more successful than Douglas-fir or white fir in these open areas. As planted seedlings survive and grow satisfactorily under a protective canopy cover, more should be planted there. Containerized Douglas-fir and white fir are suitable for this underplanting.

Contents

Page

INTRODUCTION 1

METHODS 1

RESULTS AND DISCUSSION 7
  General Observations 7
  Survival 9
  Growth 9

CONCLUSIONS 14

LITERATURE CITED 14

Introduction

The Dead Indian Plateau east of Ashland, Oregon is a notoriously poor area for forest regeneration. Naturally established seedlings are scarce or absent in many locations. Plantation failures are common. Many old clearcut areas remain poorly stocked after repeated planting attempts, and many old partially cut stands fail to regenerate naturally.

Reconnaissance of the plateau and discussion of the problem with knowledgeable local residents suggested several possible reasons for poor forest regeneration. Damage from pocket gophers, cattle, drought, and frost seemed to be the most probable causes of poor seedling survival.

The Dead Indian Plateau supports a dense population of pocket gophers (Hermann and Thomas 1963, Hooven 1971). Large populations of these rodents can be a significant cause of seedling mortality. Losses result from root clipping, stem girdling, top clipping, and seedling burial or root exposure associated with burrowing activities (Hermann and Thomas 1963, Trevis 1956). Hanson and Reid (1973) found that young trees were often debarked from 3 to 5 feet (0.9 to 1.5 m) above the ground when they were covered with snow.

Certain areas are heavily grazed by cattle, which roam freely on the plateau. No grazing data are available, but extensive trampling has been observed in some clearcut areas frequented by cattle. Partially cut stands seem less affected.

Although Minore and Carkin[1] measured only moderate plant moisture stresses in 5-foot-(2-m-) tall conifer saplings growing on the Dead Indian Plateau in 1973, these stresses were recorded under overstory canopies...not in exposed clearcut situations. They measured serious soil moisture deficits in the top 10 cm during 1974. Summer drought may seriously affect young seedlings, particularly in exposed situations where vegetative competition is severe.

Elevations of 4,000 to 6,000 feet (1 220 - 1 830 m) and gentle topography combine to create serious frost problems on the plateau. Freezing or subfreezing night temperatures are not uncommon, even in the summer. Frost-damaged seedlings and saplings can be found on many poorly stocked sites.

All of these environmental factors (gophers, cattle, drought, and frost) probably reduce seedling survival and growth on the Dead Indian Plateau. They are difficult to isolate and measure directly but can be assessed indirectly by applying treatments designed to modify or eliminate factors, one by one. Treated seedlings or plots can then be compared with each other and with untreated controls to obtain data useful in evaluating the relative importance of each environmental factor and its interaction with other factors.

Using the treated seedlings and experimental plantations described in this paper, we sought answers to the following questions:

1. Which environmental factors most influence seedling survival and growth on the Dead Indian Plateau?
2. Can seedling survival be improved by planting under overstory canopies or by using different species and/or stock types?
3. Of the three species tested, what are the best species-stock combinations for clearcuts and for partial-cut stands?

Methods

The four plantations illustrated in figures 1-4 and described in

---

[1] Unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oregon.

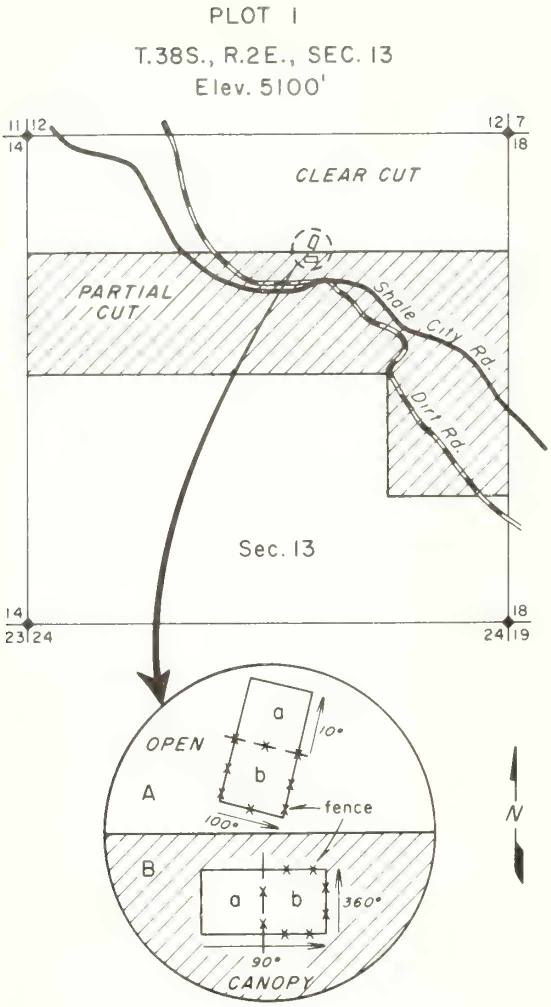


Figure 1.--Location and plot orientation of plantation 1.

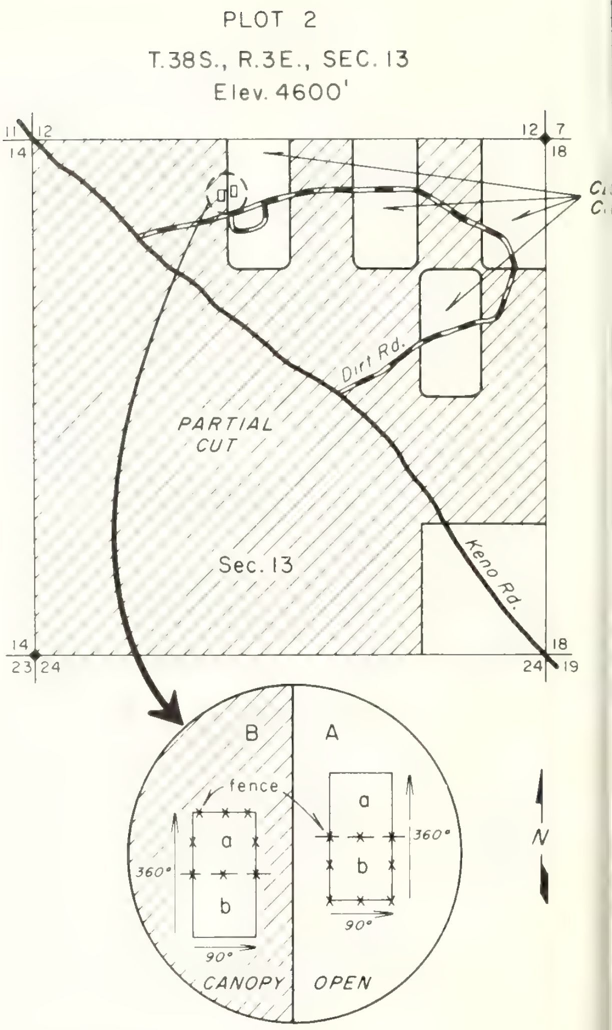


Figure 2.--Location and plot orientation of plantation 2.

table 1 were established in a split-split plot experimental design on the Dead Indian Plateau in the spring of 1975.[2] Each plantation consisted of two 100- by 200-foot (30.5- by 61-m) plots--one located under a partial-cut canopy, the other in an adjacent, previously forested open area. Each of these plots was then further divided into two 100- by 100-foot (30.5- by 30.5-m) subplots, resulting in four subplots in each plantation. One subplot under the canopy and one in the open were randomly chosen and fenced for cattle protection at each of the four plantation sites.

The following treatments were randomized on each of the four subplots (open-fenced, open-unfenced, canopy-fenced, and canopy-unfenced) in each plantation: Douglas-fir,

---

[2] Except for one plot owned by Carl Wimberly, all were on Bureau of Land Management lands.

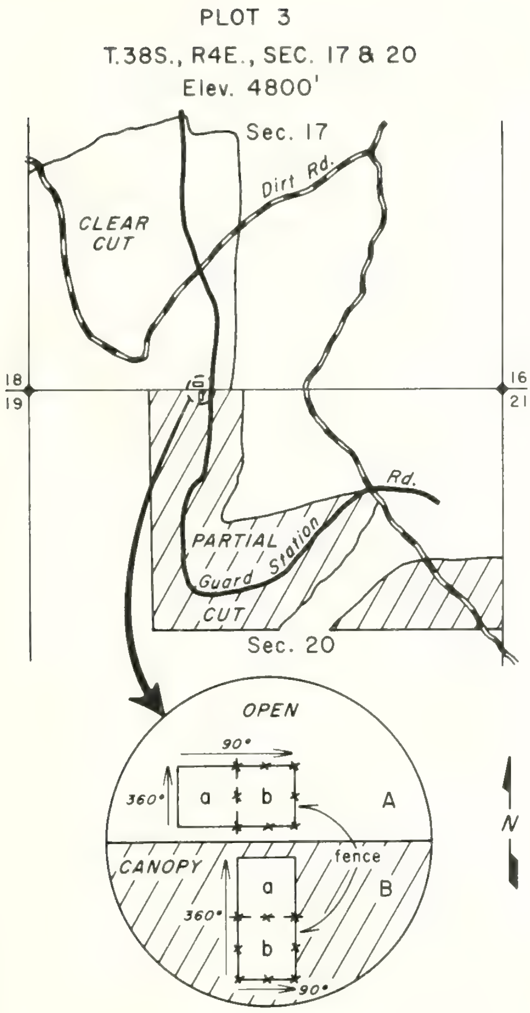


Figure 3.--Location and plot orientation of plantation 3.

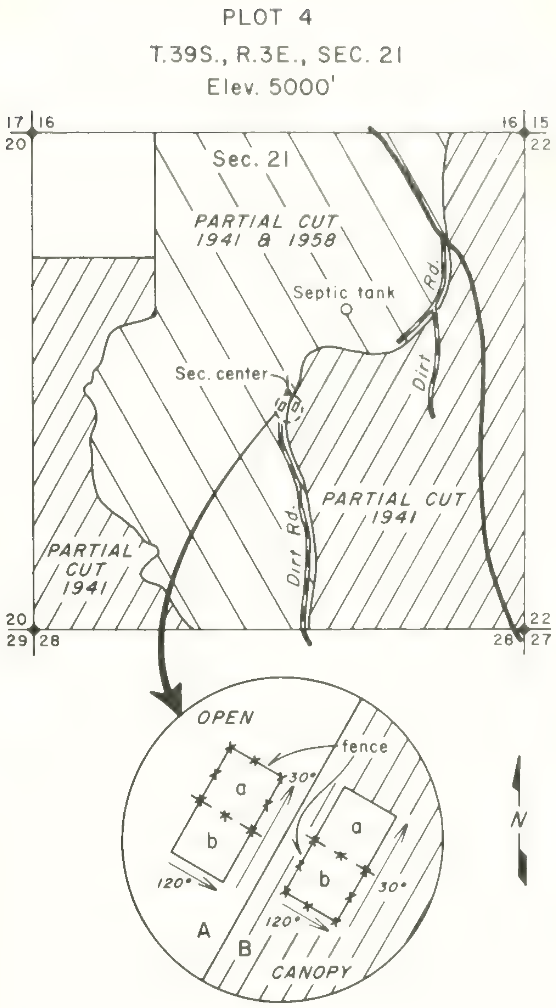


Figure 4.--Location and plot orientation of plantation 4.

Table 1--*Plantation logging dates, slopes, aspects, and partial-cut overstory characteristics*

Plantation number	Logging dates		Slope	Aspect	Partial-cut overstory		
	Open plot	Canopy plot			Basal area		Crown density
			Percent	Degrees	$ft^2/acre$	m^2/ha	Percent
1	Before 1966	1966	15	340	111	25.5	57
2	1960	1969, 1971	5	320	156	35.8	69
3	1948 - 1968	1961, 1968	5	270	164	37.6	60
4	1941, 1958	1941	0	level	155	35.6	61

white fir, or ponderosa pine; bare-root or containerized; caged or uncaged; watered or unwatered.

Each species-stock-treatment combination was replicated six times in each subplot. Thus, 144 seedlings were planted on each of the 4 subplots in each of the 4 plantations.

Soils on all four plantations were formed from basic volcanic colluvium. They are moderately deep and well drained. The soil of plantation No. 1 is slightly cobbled, with a few surface stones. Cobbles are rare in plantation No. 2 soil, and there are no surface stones. The soils of plantations No. 3 and No. 4 are very cobbly, with many surface stones. Forest regeneration was very poor on all four of the plantation areas, both in the open and under the adjacent partially cut stands.

Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*) and ponderosa pine (*Pinus ponderosa*) seedlings were grown from seed obtained by the Bureau of Land Management from the Dead Indian Plateau. A total of 2,304 seedlings (768 of each species) were used for the study. Half were bare-root, 2-0 stock and half were 1-year-old container-grown seedlings.

The bare-root Douglas-fir and white fir seedlings were grown at Wind River Nursery near Carson, Washington, and the bare-root ponderosa pine seedlings were grown at the U.S. Forest Service Bend Nursery in Oregon. Wind River seedlings were shovel-lifted on March 7, 1975, while still dormant. After lifting they were graded, bundled, and transported to Corvallis in ice-cooled chests. At Corvallis they were placed in a cold storage room maintained at 1°C. Using the same methods, the ponderosa pine seedlings were lifted at Bend on March 10 and immediately placed in cold storage with the Wind River stock.

Container stock was grown in 4-cubic inch (65.5 cc) plug-mold Styroblock containers for 1 year at Corvallis, Oregon.[3] Standard procedures were used, including weekly watering and biweekly fertilization. The container-grown seedlings were put into plastic bags in groups of 25 and placed in cold storage with the bare-root stock on March 12, 1975.

Before planting, 3-foot-(.9-m-) diameter planting spots were scalped in the open areas on all four plantations. After randomization (fig. 5), flagged wires were marked and placed on each planting spot to designate the species, stock type, and treatment to be applied.

Planting began as soon as the study areas were accessible--May 19, 1975. The seedlings were kept in iced coolers until needed, then wrapped in wet burlap as they were removed for planting. They were planted at 8- by 8-foot (2.4-by 2.4-m) spacings by predetermined, randomly assigned treatment designations at each planting spot.

Half of the seedlings were caged in .5-inch (1.3-cm) mesh hardware cloth for rodent protection. The cages consisted of two sections, each 5 inches (12.7 cm) in diameter and 1 foot (.3 m) in length, with one closed end. One section was placed underground with the seedling's roots inside at time of planting (fig. 6), while the other section was placed over the seedling in late fall and attached to the bottom half (fig. 7). This upper section was designed to eliminate aboveground damage from rodents burrowing under snow.

Seven workers planted the seedlings. Using a shovel, each progressed along an assigned row to install the species, stock types, and caging treatments as they occurred. Planting was completed on June 5, 1975. Initial seedling heights were measured, cattle fences were constructed (fig. 8), and weather stations were set up soon after planting was completed.

---

[3] Dian Wessbecher, Peyton Owston, and William Stein grew these seedlings. Their help is gratefully acknowledged.

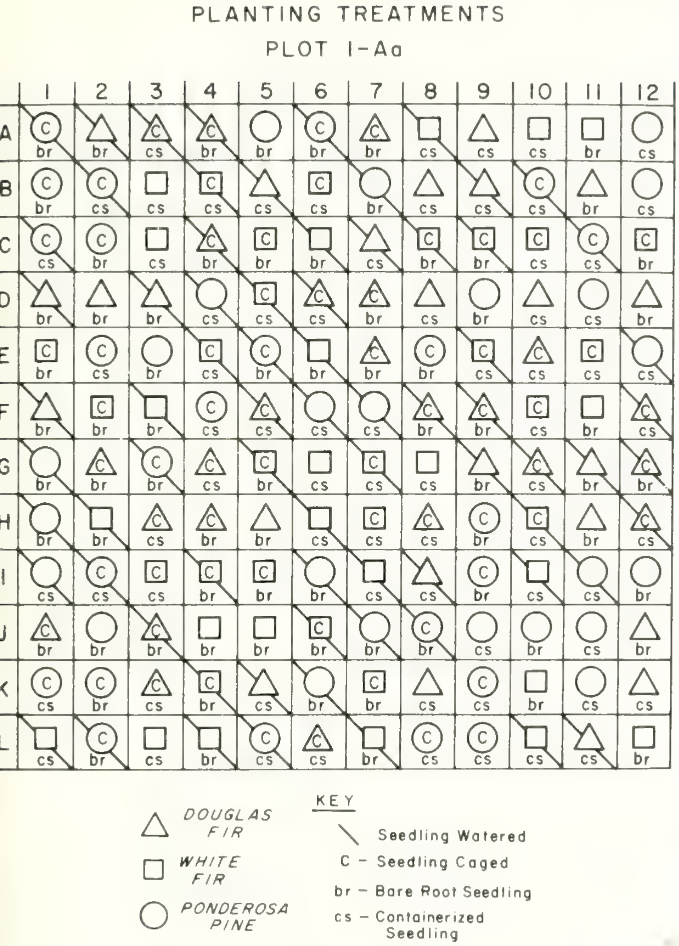
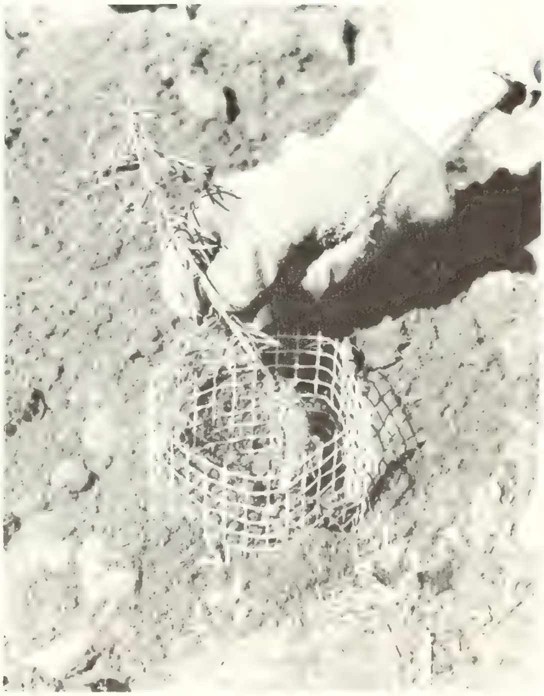


Figure 5.--Randomization of species, stock types, caging, and watering in the unfenced subplot in the open at plantation 1. (Randomization of other subplots and plantations is available on request from the Forestry Sciences Laboratory, Corvallis, Oregon.)

Figure 6.--Container-grown Douglas-fir seedling being planted in a rodent protection cage.



Temperature recorders with shielded probes were used to monitor air temperatures 8 inches (20 cm) above the soil surface. Each of the four plantations had two recorders--one under the canopy and one in the open. Summer precipitation was measured with plastic-wedge rain gages.

Half of the seedlings were irrigated during the summers of 1975 and 1976 by hand-applying 1 gallon (3.8 liters) of water per month to each. The first watering began on June 12, 1975. It was repeated monthly during the two growing seasons, with the last application on September 18, 1976.

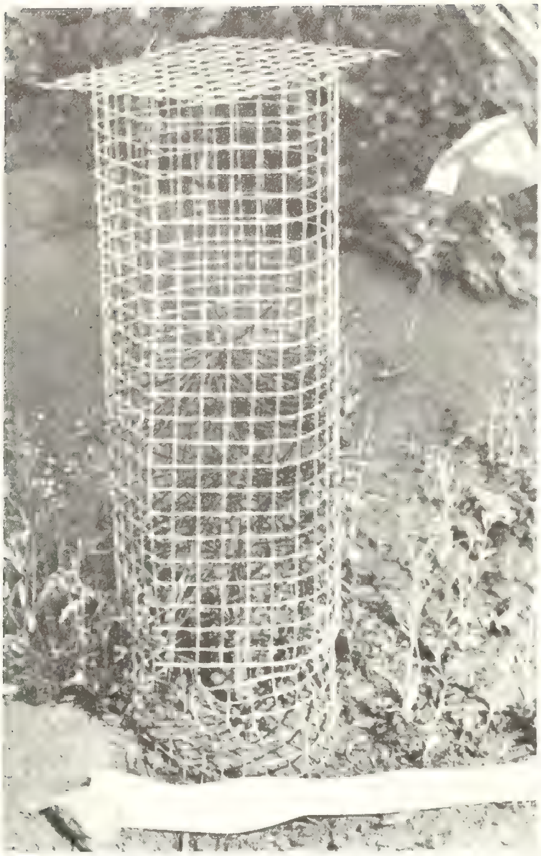


Figure 7.--Complete rodent protection cage just before removal of the upper portion on May 14, 1976. (Only the subsurface portion remained in place during growing seasons.)

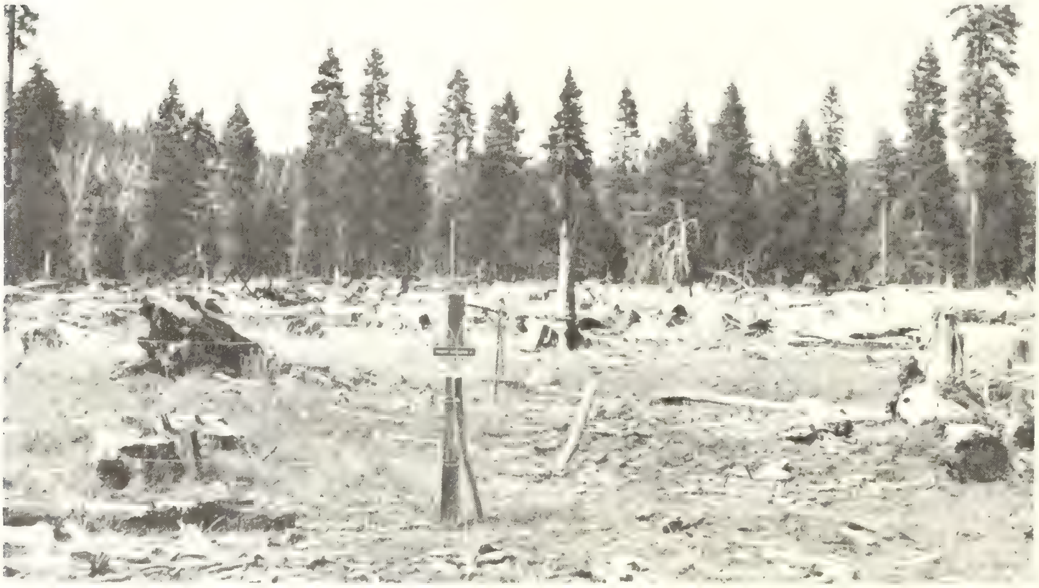


Figure 8.--Cattle fence on the open portion of plantation 2 in August, 1976. Note the difference in vegetation outside (right) and inside (left) of the fence.

The upper halves of the rodent cages were wired to the lower portions late in September, 1975. They were removed on May 14, 1976. Weather instruments were stored late in September and replaced on June 14, 1976.

Seedling survival was recorded twice--1 year after planting and again after the second growing season. Growth was recorded by remeasuring seedling heights after the second growing season. Both survival and growth then were subjected to split-split plot analyses of variance.

Seedlings were examined each month during the growing seasons (May through September) of 1975 and 1976. During these examinations, the nature, degree, and amount of damage were recorded. Lawrence and Hartwell (1961) were referred to in determining wildlife damage.

Results and Discussion

GENERAL OBSERVATIONS

Although seedlings were also damaged by drying, uprooting, breakage, burial, barking, trampling, and clipping, freezing appeared to be one of the most important factors affecting seedling mortality. It was most serious in the open, clearcut areas (table 2). Frost damage was first observed in August, 1975 on Douglas-fir and white fir seedlings--first on container-grown, then on bare-root stock. Areas receiving the most frost--the open plots--sustained the highest mortality. For example, the open plot in plantation No. 3 had 21 freezing nights and a minimum temperature of -8°C (18°F) during August, 1975; and survival was only 30 percent there. The canopied plot in this plantation had only three freezing nights and a minimum of -3°C (27°F)

Table 2--*Number of freezing ($\leq 0^{o}C$) nights on four plantations by year, month, and overstory canopy condition*[1]

Year and month	Plantation 1		Plantation 2		Plantation 3		Plantation 4	
	Open	Canopy	Open	Canopy	Open	Canopy	Open	Canopy
				Number of freezing nights				
1975								
July	0	0	2	0	5	1	2	0
August	1	0	19	7	21	3	11	1
September	1	0	25	[2]	25	1	8	0
1976								
June 15-June 30	10	2	12	9	[2]	13	5	6
July	0	2	2	[2]	[2]	13	1	1
August	1	0	3	[2]	4	1	1	4
September	2	0	7	8	14	1	5	2

[1] Temperatures were recorded 8 inches (20 cm) above the soil surface.

[2] Data missing because of thermograph malfunctions.

during the same period, with 88-percent survival. Similar temperature differences were recorded in the other plantations...the average minimum temperature for all open plots was 5°C (9°F) colder than the average minimum for canopied plots. As Cochran (1969) also observed, clearcut open areas apparently accumulate cold air. On the Dead Indian Plateau, this seems especially true where the topography is level or concave. The open plot on plantation No. 1 (15-percent slope) had only 1 freezing night during August, 1975, while plantations No. 2 and No. 3 (5-percent slopes) had 19 and 21 freezing nights, respectively.

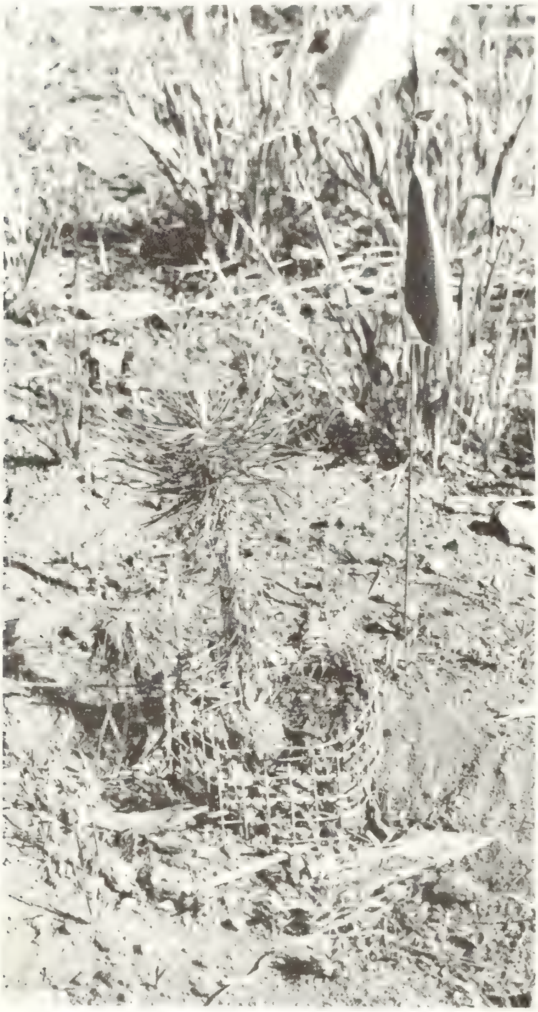


Figure 9.--Top of container plug exposed by surface erosion. This ponderosa pine seedling is in poor condition, but it survived. Most containerized seedlings died when plug tops were exposed.

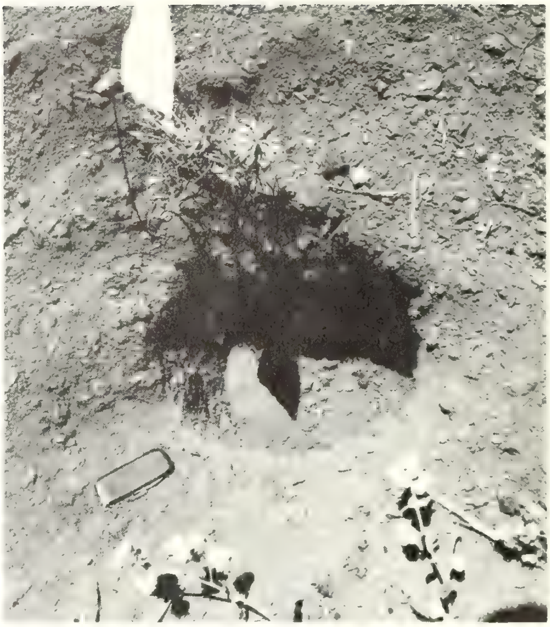


Figure 10.--Cattle-damaged seedling with hoof print.

The unusually wet summers of 1975 and 1976 obscured any beneficial effects of watering, and no drought damage was observed. Four inches (10 cm) of rain fell from June through September in 1975; 6 inches (15 cm) fell for the same period in 1976. Most of this precipitation occurred as intense summer downpours that often washed the surface soil away from containerized seedlings in the open plots, exposing plug tops (fig. 9). This seems to have initiated a wicking effect that dried out the plugs and killed affected seedlings.

A few containerized seedlings were damaged by deer trampling, and some deer browsing occurred when foliage was succulent in the spring. Cattle damage occasionally occurred from trampling on moist soil (fig. 10). Most gopher damage resulted from clipping seedlings at ground level, but the gophers also fed on roots; and a few seedlings were pulled underground, buried under gopher mounds, or uprooted by burrowing. Gopher damage usually resulted in seedling mortality.

SURVIVAL

Survival data were analyzed for two periods--at the end of 1 year from outplanting (mid-May, 1976) and at the end of the second growing season (late September, 1976). These data are herafter referred to as spring and fall survival.

As survival differences between plantations were not statistically significant, fall survival on all four plantations were combined in compiling table 3. This table summarizes treatment effects, but the large amount of data included makes interpretation difficult. Moreover, spring vs. fall comparisons are impossible. Accordingly, individual treatment, species, and stock-type comparisons were made by examining pertinent portions of the overall analysis.

Survival was better ($P<.05$)[4] under the canopied areas than in the open for both spring and fall seedling counts (table 4). Species survival also differed ($P<.01$) in both counts (table 5). Most of these differences can be attributed to better ponderosa pine survival in the clearcuts. Bare-root stock also survived better ($P<.01$) than container-grown stock in both spring and fall (table 6).

Caged seedlings survived better than uncaged seedlings in both spring and fall (table 7. Spring $P<.05$, Fall $P<.01$). The cages effectively protected seedlings (fig. 11). As the caged vs. uncaged difference was much greater in the fall than it was in the spring, rodent damage apparently was most severe during the growing season. An atypical winter in 1975-1976 may have caused this by reducing the normal winter damage associated with gophers tunnelling under snow. Local plateau residents observed that snow depths never exceeded 1 foot (.3 m), and many clearcut areas were bare all winter. Atypical, wet summers in 1975 and 1976 probably negated the watering treatment; and there were no significant survival differences associated with watering. Neither were there any significant survival differences associated with fencing.

Survival did not differ significantly among species growing under the canopy, but it differed greatly ($P<.01$) when species were compared in the open (table 8). Ponderosa pine survival was almost twice that of the other species.

There were significant canopy-caging interactions in both spring ($P<.05$) and fall ($P<.01$) measurements (table 9). Caging improved survival only in the open areas. Gophers were either more concentrated in the open or they preferred other species under the canopy for food.

Ponderosa pine benefitted more from caging than either white fir or Douglas-fir (table 10). This could be the result of a species preference by gophers, but it also may reflect the fact that most surviving seedlings in the open were ponderosa pines.

GROWTH

Excessive mortality in the open made complete statistical analyses of growth in the clearcuts impractical, so growth data for all species and all areas were analyzed for the canopied areas only. When species and treatments were combined in this canopy analysis, average growth on the four plantations differed significantly ($P<.05$):

Plantation number	Average 2-year growth (cm)
1	6.3
2	11.2
3	6.0
4	5.9

Obviously, the significant growth difference occurred on plantation No. 2.

---

[4] Probability figures in parenthese refer to levels of statistical significance.

Table 3--*Seedling survival (%) as tallied in late September, 1976 for all four plantations combined by species, stock types, and treatment*[1/]

Species and stock type	Treatment																Average all treatments
	Canopy								Open								
	Fenced				Unfenced				Fenced				Unfenced				
	Watered		Unwatered		Watered		Unwatered		Watered		Unwatered		Watered		Unwatered		
	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	Caged	Uncaged	
	Survival in percent																
Douglas-fir																	
Bare-root	91.6	95.8	100.0	87.5	83.3	91.6	91.7	95.8	29.2	16.7	16.7	25.0	37.5	16.7	29.2	25.0	58.33
Containerized	75.0	79.2	87.5	83.3	87.5	83.3	87.5	91.7	4.2	8.3	25.0	12.5	16.7	25.0	25.0	25.0	51.04
White fir																	
Bare-root	87.5	87.5	95.8	83.3	79.2	95.8	91.6	87.5	41.6	16.7	45.8	41.7	29.2	16.7	29.2	25.0	59.63
Containerized	87.6	91.6	95.8	91.6	87.5	83.3	100.0	79.2	33.4	37.5	41.7	25.0	25.0	20.8	29.2	12.5	58.86
Ponderosa pine																	
Bare-root	95.8	95.8	91.6	91.7	91.6	95.8	79.2	95.8	87.5	50.0	83.4	41.7	70.8	54.2	79.2	41.7	77.86
Containerized	87.5	75.0	100.0	83.3	79.2	91.6	95.8	75.0	70.8	50.0	79.2	50.0	58.3	29.2	54.2	37.5	69.79
Average, all species and stock types	87.50	87.48	95.12	86.78	84.72	90.23	90.97	87.50	44.45	29.87	48.63	32.65	39.58	27.10	41.00	27.78	62.58

[1/] Each percentage shown here is based upon 24 seedlings--6 in each treatment, on each of 4 plantations.

Table 4--*Survival in canopied and open areas*

Measurement season	Survival percent		Statistical significance of differences
	Canopy	Open	
Spring, 1976	92.5	50.4	P<.05
Fall, 1976	88.8	36.4	P<.05

Table 5--*Survival by species*

Measurement season	Survival percent			Statistical significance of differences
	Douglas-fir	White fir	Ponderosa pine	
Spring, 1976	65.5	66.9	82.0	P<.01
Fall, 1976	54.7	59.2	73.8	P<.01

Table 6--*Survival by stock-type*

Measurement season	Survival percent		Statistical significance of differences
	Containerized	Bare-root	
Spring, 1976	68.4	74.6	P<.01
Fall, 1976	59.9	65.3	P<.01

Table 7--*Survival by caging treatment*

Measurement season	Survival percent		Statistical significance of differences
	Not caged	Caged	
Spring, 1976	69.4	73.6	P<.05
Fall, 1976	58.7	66.5	P<.01

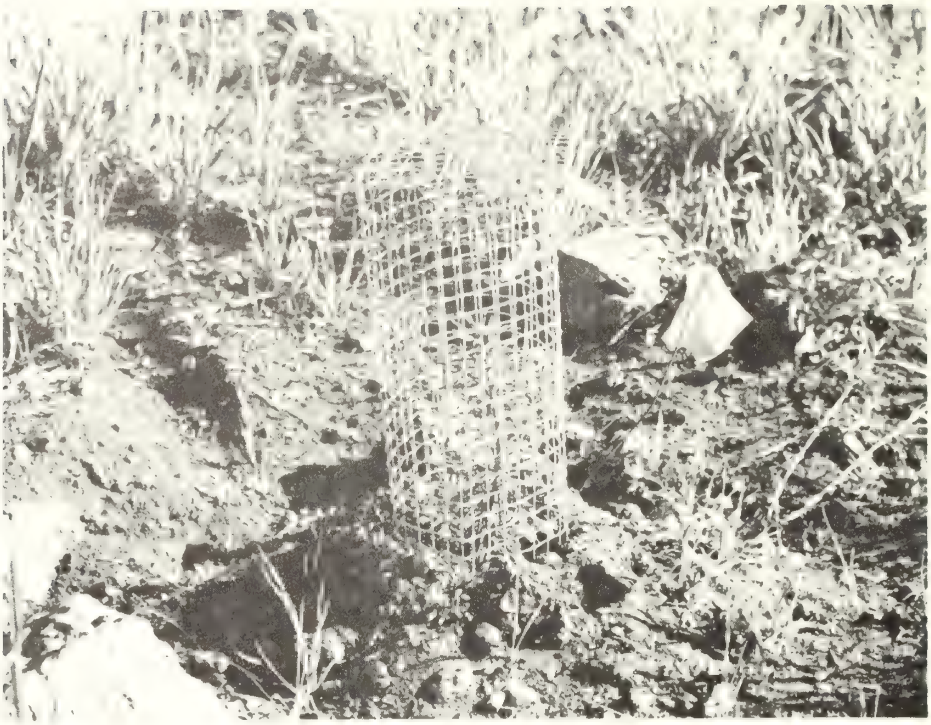


Figure 11.--Evidence of caging success. A gopher approached this seedling from the left rear (surface trench made under the snow), then burrowed completely around the cage perimeter (mounds surrounding bottom of cage). The seedling was not injured.

Caged seedlings under the canopy grew better ($P<.05$) than uncaged seedlings:

Caged	7.7-cm average growth
Uncaged	7.1-cm average growth

Caging, however, may have influenced growth through factors other than gopher protection...it probably protected seedlings from snow damage, debris from overstory trees, and deer.

When all species were combined, containerized stock grew better ($P<.01$) under the canopy than bareroot stock (table 11). There also

Table 8--*Survival in canopied and open areas, by species*[1]

Measurement season	Survival percent					
	Canopy			Open		
	Douglas-fir	White fir	Ponderosa pine	Douglas-fir	White fir	Ponderosa pine
Spring, 1976	93.0	92.4	92.2	38.0	41.4	71.9
Fall, 1976	88.3	89.1	89.1	21.1	29.4	58.6

[1] Species differences were not significant under the canopy. They were highly significant ($P< .01$) in the open.

Table 9--*Survival in canopied and open areas, by caging treatment*

Measurement season	Survival percent			
	Canopy		Open	
	Not caged	Caged	Not caged	Caged
Spring, 1976	92.7	92.4	46.0	54.9
Fall, 1976	88.0	89.6	29.3	43.4

[1] Caging differences were not significant under the canopy. They were significant in the open (Spring P<.05, Fall P<.01). The canopy-caging interactions also were statistically significant.

Table 10--*Fall survival by species and caging treatment*[1]

Caging treatment	Survival Percent		
	Douglas-fir	White fir	Ponderosa pine
Not caged	53.9	56.0	66.1
Caged	55.5	62.5	81.5

[1] The species-caging interaction was significant (P<.05).

Table 11--*Two-year growth under the canopy, by species and stock type*

Stock types	Average growth (cm)			
	Douglas-fir[1]	White fir[1]	Ponderosa pine[2]	All species[3]
Containerized	8.5	8.5	7.6	8.2
Bare-root	6.7	6.0	7.1	6.6
All stock types[2]	7.6	7.2	7.3	7.4

[1] The difference was significant (P<.05).

[2] The differences were not statistically significant.

[3] The difference was highly significant (P<.01).

was a species-stock type interaction ($P<.05$). Containerized Douglas-fir and white fir seedlings grew significantly better than bare-root stock. Ponderosa pine seedlings did not. When stock types were combined, the growth differences among species were not statistically significant.

Fencing and watering had no significant effects upon seedling growth. If the summers of 1975 and 1976 had been more typical (drier), growth differences probably would have been greater.

Conclusions

Several variables affected seedling survival and growth in these experimental plantations, but frost and pocket gophers seemed to be the most important. Both were strongly associated with the open areas created by overstory canopy removal. Therefore, the presence or absence of an overstory canopy apparently is the single most important factor in determining plantation success or failure on the Dead Indian Plateau. Plantations in open, clearcut areas are less likely to succeed then those established under overstory canopies.

In clearcut areas, ponderosa pine seedlings survive better than white fir or Douglas-fir seedlings; however, other frost hardy species should be investigated. Cochran and Berntsen (1973) reported lodgepole pine seedlings to be even more cold tolerant than those of ponderosa pine, and Black and Hooven (1977) recorded better survival of lodgepole pine, ponderosa pine, and incense-cedar than of Douglas-fir and white fir on Dead Indian clearcuts. Selected local Douglas-fir stock with inherent frost hardiness should also be tried. In localized areas, such as clearcuts on south slopes, shading and/or frost protection of individual seedlings may be beneficial. Although not tested on the experimental plantations, this has been observed elsewhere on the plateau where live and dead shade were related to seedling survival and growth (Minore 1971).

As planted seedlings survive and grow satisfactorily under a protective canopy cover, more should be planted there in the Dead Indian area. Optimum timing has not been determined yet, but overstory removal should be delayed until after seedlings are fully established and large enough to withstand severe frosts. As measured by spherical densiometer, optimum overstory density for natural regeneration is about 60 percent (Minore and Carkin 1977). The minimum shelterwood overstory density required for satisfactory plantation survival should be determined and incorporated into management practices.

Containerized Douglas-fir and white fir seedlings grew best under overstory canopies on the experimental plantations. This indicates that these species may be underplanted successfully as containerized stock; however, further study of understory planting and overstory removal is needed. Seedling survival and response after overstory canopy removal should be understood better before this or any other underplanting technique is extensively used.

Literature Cited

Black, Hugh C., and Edward F. Hooven.
1977. Effects of herbicide-induced habitat changes on pocket gophers in southwestern Oregon. Proc. 29th Ann. Calif. Weed Conf., Jan. 1977, p. 119-127.

Cochran, P. H.
1969. Lodgepole pine clearcut size affects minimum temperatures near the soil surface. USDA For. Serv. Res. Pap. PNW-86, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H., and Carl M. Berntsen.
1973. Tolerance of lodgepole and ponderosa pine seedlings to low night temperatures. For. Sci. 19(4):272-280.

Hanson, Richard M., and Vincent H. Reid.
1973. Distribution and adaptations of pocket gophers. p. 1-19 *In* Pocket gophers and Colorado

mountain rangeland. Colorado State Univ. Exp. Stn., Fort Collins, Colorado. Bulletin No. 554. 90 p.

Hermann, Richard K., and Harold A. Thomas.
1963. Observations on the occurrence of pocket gophers in southern Oregon pine plantations. J. For. 61(7):527-529.

Hooven, Edward F.
1971. Pocket gopher damage on ponderosa pine plantations in southwestern Oregon. J. of Wildlife Manage. 35(2):346-353.

Lawrence, W. H., and Harry D. Hartwell.
1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. Western Forestry and Conservation Assoc. Portland, Oreg. 44 p.

Minore, Don.
1971. Shading benefits Douglas-fir in southwestern Oregon cutover area. Tree Planters' Notes 22(1):22-23.

Minore, Don, and Richard E. Carkin.
1978. Vegetative indicators, soils, overstory canopy, and natural regeneration after partial cutting in the Dead Indian Plateau area of southwestern Oregon. USDA For. Serv. Res. Note PNW-316, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Trevis, L., Jr.
1956. Pocket gophers and seedlings of red fir. Ecology 37:379-381.

GPO 986-674

Williamson, Denis M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Survival and growth of Douglas-fir, white fir, and ponderosa pine seedlings were studied in experimental plantations. Both bare-root and containerized seedlings were tested in the open and under partial-cut canopy. Some were caged, some watered, and some fenced. Survival of all species was much better under the partial-cut canopy than in the open, where ponderosa pine survived better than Douglas-fir or white fir. Containerized Douglas-fir and white fir seedlings grew best under the canopy. Underplanting is recommended on the Dead Indian Plateau.

KEYWORDS: Seedling survival, seedling growth, bare-root nursery stock, container nursery stock, Douglas-fir, white fir, ponderosa pine, Oregon (Dead Indian Plateau).

Williamson, Denis M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Survival and growth of Douglas-fir, white fir, and ponderosa pine seedlings were studied in experimental plantations. Both bare-root and containerized seedlings were tested in the open and under partial-cut canopy. Some were caged, some watered, and some fenced. Survival of all species was much better under the partial-cut canopy than in the open, where ponderosa pine survived better than Douglas-fir or white fir. Containerized Douglas-fir and white fir seedlings grew best under the canopy. Underplanting is recommended on the Dead Indian Plateau.

KEYWORDS: Seedling survival, seedling growth, bare-root nursery stock, container nursery stock, Douglas-fir, white fir, ponderosa pine, Oregon (Dead Indian Plateau).

Williamson, Denis M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Survival and growth of Douglas-fir, white fir, and ponderosa pine seedlings were studied in experimental plantations. Both bare-root and containerized seedlings were tested in the open and under partial-cut canopy. Some were caged, some watered, and some fenced. Survival of all species was much better under the partial-cut canopy than in the open, where ponderosa pine survived better than Douglas-fir or white fir. Containerized Douglas-fir and white fir seedlings grew best under the canopy. Underplanting is recommended on the Dead Indian Plateau.

KEYWORDS: Seedling survival, seedling growth, bare-root nursery stock, container nursery stock, Douglas-fir, white fir, ponderosa pine, Oregon (Dead Indian Plateau).

Williamson, Denis, M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Survival and growth of Douglas-fir, white fir, and ponderosa pine seedlings were studied in experimental plantations. Both bare-root and containerized seedlings were tested in the open and under partial-cut canopy. Some were caged, some watered, and some fenced. Survival of all species was much better under the partial-cut canopy than in the open, where ponderosa pine survived better than Douglas-fir or white fir. Containerized Douglas-fir and white fir seedlings grew best under the canopy. Underplanting is recommended on the Dead Indian Plateau.

KEYWORDS: Seedling survival, seedling growth, bare-root nursery stock, container nursery stock, Douglas-fir, white fir, ponderosa pine, Oregon (Dead Indian Plateau).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives – as directed by Congress – to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

Height Growth and Site Index Estimates for NOBLE FIR in High-Elevation Forests of the Oregon-Washington Cascades

CLEMSON UNIVERSITY LIBRARY
DEC 21 197
TECH. & AGR. DIV.

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service
Portland, Oregon

Introduction

This paper presents height growth and site index estimation curves for dominant noble fir (*Abies procera* Rehd.) in high-elevation forests of the Oregon-Washington Cascade Range. These curves replace those of DeMars et al. (1970). They differ through the incorporation of additional data, the use of new methods of analysis (Curtis et al. 1974a, 1974b), and the presentation of metric equations, curves, and tables.

These equations and curves are based on stem analyses (Herman et al. 1975) of selected dominant trees at 60 locations between McKenzie Pass in central Oregon and Stevens Pass in north-central Washington (fig. 1). All locations represent unmanaged stands, mainly old growth within the "*Abies amabilis* zone" of Franklin and Dyrness (1973). Similar data were collected concurrently for associated species; curves for associated Douglas-fir have been given by Curtis et al. (1974b), and curves for other species are planned.

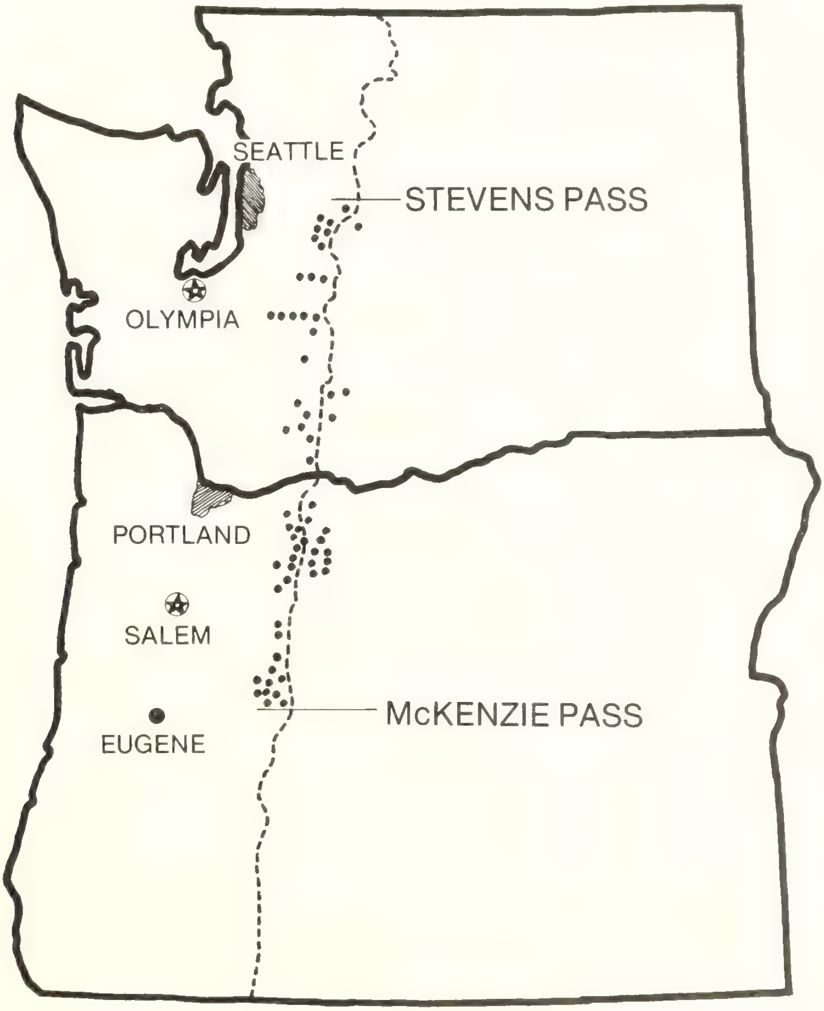


Figure 1.--Geographic distribution of the noble fir selected for stem analysis and used sample in development of height growth and site index estimation curves.

Contents

Page

INTRODUCTION 1

DATA 2

ANALYSIS 2
  Height Growth Equations 3
  Site Index Estimation Curves 4

DISCUSSION 13
  Height Growth Curves 13
  Site Index Estimation Curves 13
  Possible Bias 13
  Application of Curves 14

LITERATURE CITED 14

HEIGHT GROWTH AND SITE INDEX ESTIMATES FOR NOBLE FIR IN HIGH-ELEVATION FORESTS OF THE OREGON-WASHINGTON CASCADES

Reference Abstract

Herman, Francis R., Robert O. Curtis, and Donald J. Demars.
1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. USDA For. Serv. Res. Pap. PNW-243, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Height growth and site index estimation equations and corresponding curves were derived from stem analyses of *Abies procera* Rehd. in the Cascade Range of Oregon and Washington. These incorporate additional data and new site index estimation procedures and replace previously published curves. Two sets of height growth and site index estimation curves and tables are given--one set with U.S. units and another set with metric units.

KEYWORDS: Site index -)stand height/age, increment (height), altitude (-site, noble fir, *Abies procera*, Oregon (Cascade Range), Washington (Cascade Range).

RESEARCH SUMMARY

Research Paper PNW-243

1978

Height growth and site index stimation equations and corresponding urves for noble fir (*Abies procera* ehd.) were developed from stem nalysis data from 60 plots located etween McKenzie Pass in central regon and Stevens Pass in north-entral Washington. This information eplaces earlier information presented n 1970.

Height growth estimation curves btained by regressing height on site ndex and age differ from site index stimation curves obtained by reressing site index on height and ge. The former provides estimates f expected heights of noble fir at ifferent ages for stands of speciied site index. The latter provides stimates of noble fir site index for stands of known present age and height.

The new curves and tabular data can be used for estimating relative site quality of noble fir within the geographic zone represented by the basic data. Because the curves were based on the tallest, undamaged dominant in one-fourth acre (0.1 ha), the tallest, undamaged dominant should also be selected when the site index of any similar-size upper-slope forest area is estimated.

These curves for high-elevation noble fir will provide a basis for development of growth and yield estimates for true fir and hemlock (*Abies* spp. and *Tsuga* spp.) of the Oregon-Washington Cascade Range.

Data

Each field location was selected in an area of uniform site and stand conditions, usually about one-fourth acre (0.1 ha) within a stand or group of trees in which the dominants were estimated to be of a single age class. The single tallest undamaged dominant of each species present was felled. Sections were cut at stump, at 4.5 feet (1.4 m), and at intervals up the stem (usually 18 feet (5.5 m) in the merchantable portion of large trees, and shorter intervals in small trees and tops).

Heights were plotted over ages. Interpolated values of heights at successive 10-year intervals of age at breast height (age bh) were the values used in analyses. Examination of these graphs and comparison of tree ages led to rejection of several noble fir trees because of evidence of early damage or suppression, or differences in age class. Data from trees used in the analyses are summarized by number of sample trees present at successive ages bh in the following tabulation. The number of trees by classes of height attained at age 100 (H100) is given in figure 2.

Age at breast height	Number of trees
10-100	60
150	55
200	48
250	34
300	14
350	5
400	2

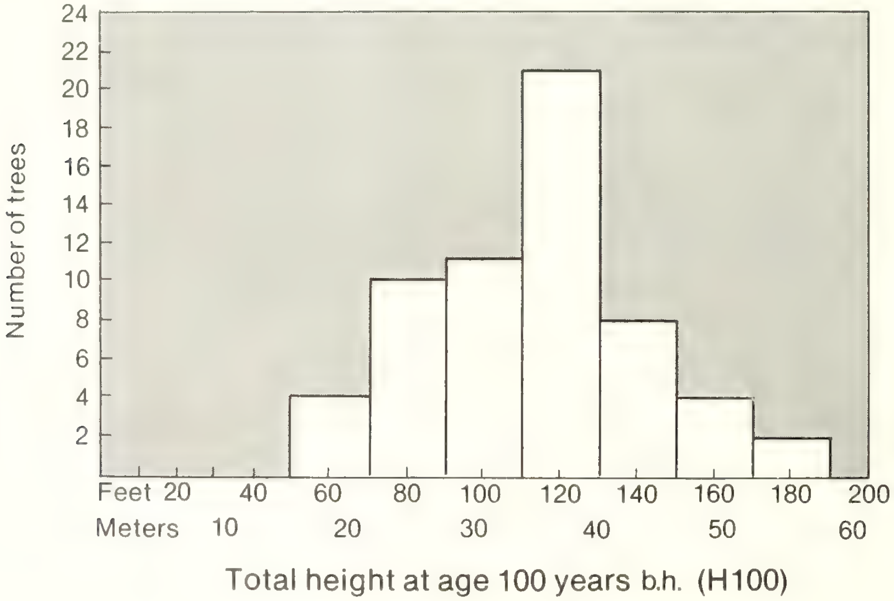


Figure 2.--Number of noble fir trees used in analysis sample by classes of H100 (attained height at age 100 years bh).

Analysis

The analysis followed, with minor differences, the general procedure used with Douglas-fir (Curtis et al. 1974b).

All ages indicated in the following discussions are in years from breast height (age bh). Site index is average height at age bh of 100 years of selected trees. Individual sample tree height at age 100 bh which is an estimate of site index is symbolized as H100; tree heights at other ages as H. The variables are age bh, H100-4.5, and H-4.5. Subtraction of 4.5 feet (1.37 m) provides a common origin for height and age scales at breast height.

HEIGHT GROWTH EQUATIONS

Preliminary Curves

The regressions $(H - 4.5) = a + b\ (H100 - 4.5)$ and $(H - 4.5) = a + b\ (H100 - 4.5) + c\ (H - 4.5)^2$, using 4.5 feet[1] for breast height, were fitted to data for individual 10-year intervals of age bh. These provided estimates for successive intervals of H100 which, when connected, gave unsmoothed trends over age--used as guides in selecting suitable equations (Heger 1968; Curtis et al. 1974a, 1974b)--and standard errors of estimate (SEE)--used as the basis for the weighting factor in subsequent computations.

Although curvilinearity was slight, the squared term was significant for ages 130+.

Trends over age were consistent and reasonably smooth up to age bh = 260 years. Beyond this age, trends became erratic and somewhat unreasonable. This condition is due to the combination of very limited sample size and prolonged height growth of a few extremely old trees. Therefore, in subsequent analyses, data for ages >260 years were omitted. Portions of the final curves and tables representing ages >260 years are extrapolations.

Height Growth Regression Fitted to Pooled Data

A series of trial fits to values read from the preliminary curves indicated that the inverse polynomial

$$H - 4.5 = (\text{age bh})^2/[a + b(\text{age bh}) + c(\text{age bh})^2],$$

previously used by DeMars et al. (1970), would satisfactorily represent the height-age relationship for given values of site index.

The condition that H = H100 at age bh = 100 was introduced by writing

$$c = 1.0 - a\ (1/100)^2 - b\ (1/100);$$

where,

$$w(H - 4.5) = w(H100 - 4.5)/[a(1/\text{age bh})^2 + b(1/\text{age bh}) + 1.0 - 0.0001(a) - 0.01(b)]$$ [2]

and

w = 1/SEE, a weighting factor, and
a, b are unknown functions of H100.

---

[1] Regressions expressed in metric equivalents:

$(H_m - 1.37 = a + b\ (H100_m - 1.37)$ and $(H_m - 1.37) = a + b\ (H100_m - 1.37) + c\ (H100_m - 1.37)^2$.

Regression coefficients appearing in equations are changed where necessary to produce valid metric expressions. Curves expressed in U.S. measurements will be slightly different in reference heights; i.e., site index 60 curves in feet have no exact counterpart in selected metric curves. Therefore, separate equations are given for feet and for meters.

[2] Instructions for equation development is given by Curtis et al. 1974a, p. 79.

This model was fitted to the pooled data for ages bh = 20, 40, etc. Odd-numbered decades were omitted to reduce running time of the nonlinear least squares fitting program. Successive trials of a number of functions for "a" and "b" led to the following equations:

Equation I, in feet:

$$H = 4.5 + (H100 - 4.5)/[a(1/x)^2 + b(1/x) + 1.0 - 0.0001(a) - 0.01(b)];$$

where,

x = age bh,

$a = -564.38 + 22.25\ (H100 - 4.5) - 0.04995\ (H100 - 4.5)^2$, and

$b = 6.80 + 2843.21\ (H100 - 4.5)^{-1} + 34735.54\ (H100 - 4.5)^{-2}$.

Standard error of estimate of the transformed variable $w(H - 4.5)$ was 1.0055.

Height estimates by this equation are given in table 1, and corresponding height growth curves are shown in figure 3.

Equation I, in meters:

$$H_m = 1.37 + [H100_m - 1.37]/[a(1/x)^2 + b(1/x) + 1.0 - 0.0001(a) - 0.01(b)];$$

where,

x = age bh,

$a = -564.38 + 73.0044(H100_m - 1.37) - 0.5376(H100_m - 1.37)^2$, and

$b = 6.80 + 866.612(H100_m - 1.37)^{-1} + 3227.05\ (H100_m - 1.37)^{-2}$.

Height estimates in meters are given in table 2 and corresponding height growth curves are shown in figure 4.

SITE INDEX ESTIMATION CURVES

Preliminary Curves

The regressions $(H100 - 4.5) = a + b(H - 4.5)$ and $(H100 - 4.5) = a + b(H - 4.5) + c(H - 4.5)^2$ were fitted to data for individual successive 10-year intervals of age bh. Trends of coefficients over age were used as guides in selecting suitable equation forms for expression of the $H100 = f(H, \text{age})$ relationship for all combined data. The squared term was significant only for ages of 110 years and above. Curvilinearity was slight within that range.

Site Index Estimation Equations Fitted to Pooled Data

To simplify curve fitting, we fitted the subsequent regressions of H100 on age bh and height to the pooled data in two segments: (1) ages less than 100 years bh and (2) ages over 100 years bh.

(1) Equations for ages 0-100 years: The regression of H100 - 4.5 on H - 4.5 and age bh was fitted as a weighted regression conditioned to pass through H100 = H at age bh = 100 (Curtis et al. 1974b), which--after simplication--can be written as:

Equation II, in feet:

$$\hat{H}100 = a + b(H - 4.5);$$

where,

$a = 4.5 + 0.2145(100 - \text{age bh}) + 0.0089(100 - \text{age bh})^2$ and

$b = 1.0 + 0.00386(100 - \text{age bh}) + 1.2518(100 - \text{age bh})^5/(10)^{10}$,

with standard error of estimate of the transformed variable $w(H100 - H)$ being 0.9842.

Table 1--*Expected heights for indicated ages at breast height (bh) for values of H100 (total height in feet at index age 100)*[1]

e bh	Height (feet) at index age 100										
	60	70	80	90	100	110	120	130	140	150	160
rs	Feet										
	9	10	10	10	11	11	11	11	12	12	12
	16	18	20	21	23	24	25	26	28	29	30
	22	26	30	33	36	39	41	44	46	49	51
	29	34	39	44	48	53	57	61	65	69	73
	35	41	48	54	60	65	71	76	82	87	92
	40	48	55	63	70	77	83	90	97	103	110
	46	54	62	71	79	87	94	102	110	117	125
	51	60	69	78	87	95	104	113	121	130	138
	55	65	75	84	94	103	113	122	131	141	150
	60	70	80	90	100	110	120	130	140	150	160
	64	75	85	95	106	116	127	137	148	158	169
	68	79	89	100	111	122	132	143	154	165	176
	72	83	93	104	115	126	138	149	160	172	183
	76	86	97	108	119	131	142	154	166	178	189
	79	90	101	112	123	135	147	159	171	183	195
	83	93	104	115	127	139	151	163	175	187	199
	86	96	107	118	130	142	154	166	179	191	204
	89	99	110	121	133	145	157	170	182	195	208
	92	102	112	124	136	148	160	173	186	198	211
	95	104	115	126	138	150	163	176	188	201	214
	97	107	117	128	140	153	165	178	191	204	217
	100	109	119	131	142	155	168	181	194	207	220
	102	111	121	133	145	157	170	183	196	209	223
	105	113	123	134	146	159	172	185	198	211	225
	107	115	125	136	148	161	174	187	200	213	227
	109	117	127	138	150	162	175	188	202	215	229
	111	119	128	139	151	164	177	190	204	217	231
	113	120	130	141	153	165	178	192	205	219	232
	115	122	131	142	154	167	180	193	207	220	234
	117	123	133	144	155	168	181	194	208	222	236
	119	125	134	145	157	169	182	196	209	223	237
	121	126	135	146	158	170	184	197	211	224	238
	123	128	136	147	159	172	185	198	212	226	239
	124	129	138	148	160	173	186	199	213	227	241
	126	130	139	149	161	174	187	200	214	228	242
	127	131	140	150	162	175	188	201	215	229	243
	129	133	141	151	163	175	189	202	216	230	244
	130	134	142	152	164	176	189	203	217	231	245
	132	135	143	153	165	177	190	204	218	232	246
	133	136	144	154	165	178	191	205	218	232	246

---

[1] From equation I (in feet). Values correspond to height growth curves shown in figure 3.

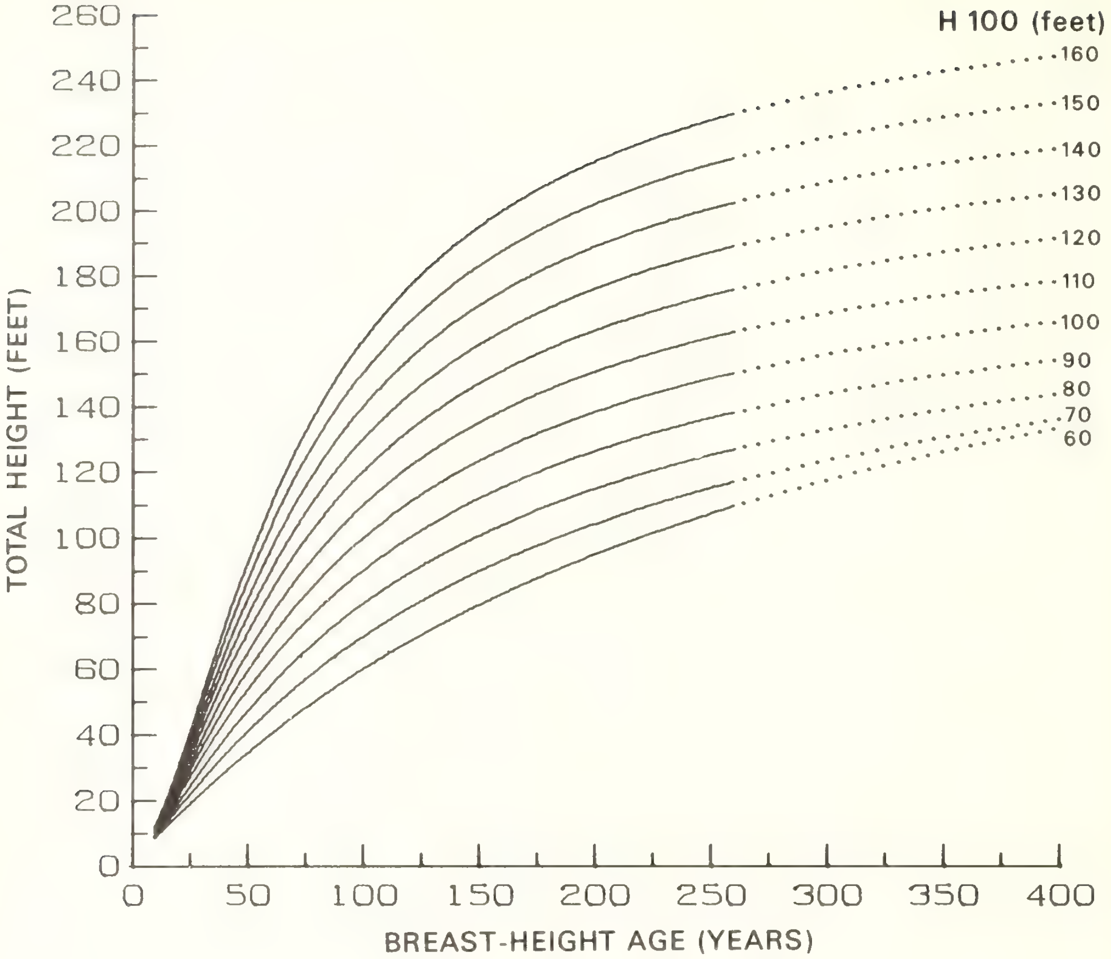


Figure 3.--Height growth curves for noble fir (in feet) corresponding to equation I (in feet). Note: These curves express the pattern of height growth of dominant trees in relation to age, within even-aged stands. They should be used for expressing height development in the construction of yield tables or yield functions representing average development of even-aged stands actually attaining specified heights at index age 100 (site indices). Use these curves where height growth and yield determinations are to be expressed in feet.

Corresponding values are shown in table 3 and figure 5, for ages bh of 10 through 100 years.

Equation II, in meters:

$$\hat{H}100_m = a + b(H_m - 1.37);$$

where,

$a = 1.37 + 0.0654(100 - \text{age bh}) + 0.0027(100 - \text{age bh})^2$ and

$b = 1.0 + 0.00386(100 - \text{age bh}) + 1.2518(100 - \text{age bh})^5/10^{10}$.

Table 2--*Expected heights for indicated ages at breast height (bh) for values of H100 (total height in meters at index age 100)*[1]

Height (meters) at index age 100										
20	23	26	29	32	35	38	41	44	47	50
					Meters					
2.8	3.0	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.7	3.8
5.1	5.7	6.2	6.7	7.1	7.5	7.9	8.2	8.6	8.9	9.3
7.4	8.5	9.5	10.4	11.3	12.1	12.9	13.7	14.4	15.2	15.9
9.6	11.2	12.6	14.0	15.4	16.6	17.9	19.1	20.2	21.4	22.6
11.7	13.6	15.5	17.3	19.0	20.7	22.4	24.0	25.6	27.2	28.8
13.6	15.8	18.0	20.2	22.3	24.3	26.4	28.4	30.3	32.3	34.3
15.4	17.9	20.4	22.8	25.2	27.5	29.9	32.2	34.5	36.8	39.1
17.0	19.7	22.4	25.1	27.7	30.3	32.9	35.5	38.1	40.7	43.2
18.6	21.4	24.3	27.2	30.0	32.8	35.6	38.4	41.2	44.1	46.9
20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0
21.3	24.4	27.5	30.7	33.8	36.9	40.1	43.2	46.4	49.6	52.7
22.6	25.8	28.9	32.2	35.4	38.7	41.9	45.2	48.5	51.8	55.1
23.8	27.0	30.2	33.5	36.8	40.2	43.6	47.0	50.4	53.8	57.3
24.9	28.1	31.4	34.7	38.2	41.6	45.1	48.6	52.1	55.6	59.1
26.0	29.2	32.5	35.9	39.3	42.9	46.4	50.0	53.6	57.2	60.8
27.0	30.1	33.5	36.9	40.4	44.0	47.6	51.3	54.9	58.6	62.3
27.9	31.1	34.4	37.9	41.4	45.0	48.7	52.4	56.1	59.9	63.6
28.8	31.9	35.2	38.7	42.3	46.0	49.7	53.5	57.2	61.1	64.9
29.6	32.7	36.0	39.5	43.2	46.8	50.6	54.4	58.2	62.1	66.0
30.4	33.5	36.8	40.3	43.9	47.6	51.4	55.3	59.2	63.1	67.0
31.2	34.2	37.5	41.0	44.6	48.4	52.2	56.1	60.0	63.9	67.9
31.9	34.8	38.1	41.6	45.3	49.1	52.9	56.8	60.8	64.7	68.7
32.6	35.5	38.7	42.3	45.9	49.7	53.6	57.5	61.5	65.5	69.5
33.2	36.1	39.3	42.8	46.5	50.3	54.2	58.1	62.1	66.2	70.2
33.9	36.6	39.9	43.4	47.0	50.8	54.8	58.7	62.7	66.8	70.8
34.5	37.2	40.4	43.9	47.5	51.4	55.3	59.3	63.3	67.4	71.4
35.0	37.7	40.9	44.3	48.0	51.8	55.8	59.8	63.8	67.9	72.0
35.6	38.2	41.3	44.8	48.5	52.3	56.2	60.3	64.3	68.4	72.5
36.1	38.6	41.7	45.2	48.9	52.7	56.7	60.7	64.8	68.9	73.0
36.6	39.1	42.2	45.6	49.3	53.1	57.1	61.1	65.2	69.3	73.5
37.1	39.5	42.5	46.0	49.7	53.5	57.5	61.5	65.6	69.8	73.9
37.6	39.9	42.9	46.3	50.0	53.9	57.8	61.9	66.0	70.2	74.3
38.0	40.3	43.3	46.7	50.3	54.2	58.2	62.2	66.4	70.5	74.7
38.5	40.6	43.6	47.0	50.7	54.5	58.5	62.6	66.7	70.9	75.1
38.9	41.0	43.9	47.3	51.0	54.8	58.8	62.9	67.0	71.2	75.4
39.3	41.3	44.2	47.6	51.3	55.1	59.1	63.2	67.3	71.5	75.7
39.7	41.7	44.5	47.9	51.5	55.4	59.4	63.5	67.6	71.8	76.0
40.0	42.0	44.8	48.2	51.8	55.6	59.6	63.7	67.9	72.1	76.3
40.4	42.3	45.1	48.4	52.0	55.9	59.9	64.0	68.2	72.4	76.6
40.7	42.6	45.3	48.7	52.3	56.1	60.1	64.2	68.4	72.6	76.8

/From equation I (in meters). Values correspond to height growth curves shown in figure 4.

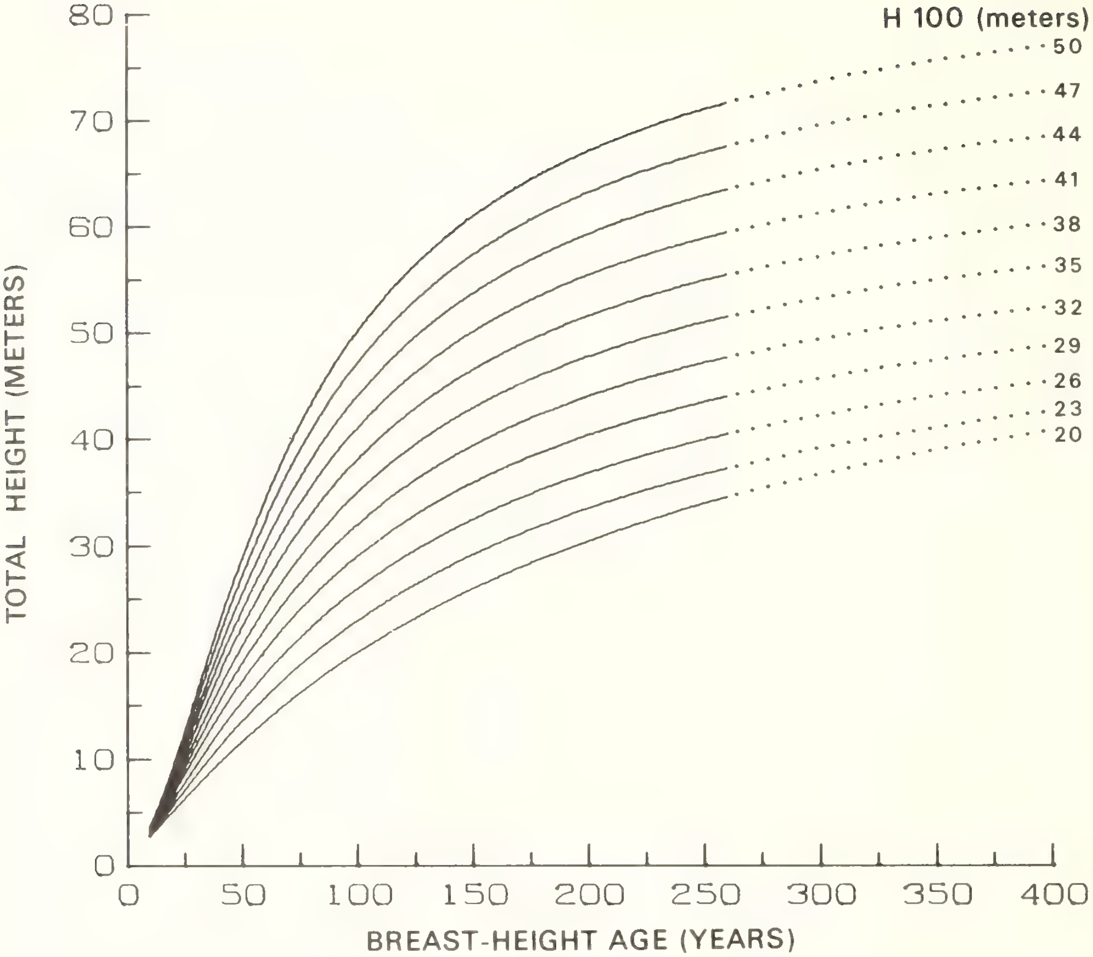


Figure 4.--Height growth curves for noble fir (in meters) corresponding to equation I (in meters). Note: These curves express the pattern of height growth of dominant trees in relation to age, within even-aged stands. They should be used for expressing height development in the construction of yield tables or yield functions representing average development of even-aged stands actually attaining specified heights at index age 100 (site indices). Use these curves where height growth and yield determinations are to be expressed in meters.

Corresponding metric values are shown in table 4 and figure 6, for ages bh of 10 through 100 years.

(2) Equations for ages 100+ years bh: The regression of $H100 - 4.5$ on age bh, $H - 4.5$, and $(H - 4.5)^2$ was fitted as a weighted and conditioned regression, using only values for ages 80, 90, and 110 to 260 years. (Ages 80 and 90 were included to insure approximate equality of slopes at age 100 for this curve and also for ages under 100 years.) To insure reasonable behavior at older ages, we expressed coefficients as polynomials in $(1/\text{age bh})^n$, $n \geq 0$, and equals 1/2, 1, 2, 3, etc., sequence in a series of stepwise trials.

Table 3--*Ages bh and total heights corresponding to indicated estimates of H100 (height at index age 100)*[1]

	Height (feet) at index age 100										
h	60	70	80	90	100	110	120	130	140	150	160
s	Feet										
	[2]-12	-7	-2	2	7	11	16	21	26	31	35
	-5	0	5	11	17	23	29	34	40	46	52
	2	9	16	23	29	36	43	50	57	63	70
	13	20	28	35	43	50	58	65	73	80	88
	23	31	39	47	55	63	72	80	88	96	104
	33	41	50	58	67	75	84	93	101	110	118
	41	50	59	68	77	86	95	104	113	122	131
	49	58	67	77	86	95	104	114	123	132	142
	55	65	74	84	94	103	113	122	132	142	151
	60	70	80	90	100	110	120	130	140	150	160
	64	74	85	95	105	116	126	137	147	158	168
	68	78	89	100	110	121	132	143	154	165	176
	71	82	93	104	115	126	137	148	160	171	183
	74	85	96	107	119	130	142	153	165	177	189
	77	88	99	111	122	134	146	158	170	183	195
	79	91	102	114	126	138	150	163	175	188	201
	82	93	105	117	129	141	154	167	180	193	207
	84	96	108	120	132	145	158	171	184	198	212
	86	98	110	122	135	148	161	175	188	203	217
	88	100	112	125	138	151	164	178	192	207	222
	90	102	114	127	140	154	167	182	196	211	227
	91	104	116	129	143	156	170	185	200	216	232
	93	105	118	131	145	159	173	188	204	220	236
	94	107	120	133	147	161	176	191	207	224	241
	96	109	122	135	149	163	178	194	210	227	245
	97	110	123	137	151	166	181	197	213	231	250
	99	111	125	139	153	168	183	200	217	235	254
	100	113	126	140	155	170	186	202	220	238	258
	101	114	128	142	157	172	188	205	223	242	262
	102	115	129	143	158	174	190	207	226	245	266
	103	116	130	145	160	176	192	210	228	248	270
	104	118	132	146	161	177	194	212	231	252	274
	105	119	133	147	163	179	196	214	234	255	279
	106	120	134	149	164	181	198	217	236	258	283
	107	121	135	150	166	182	200	219	239	262	287
	108	122	136	151	167	184	202	221	242	265	291
	109	123	137	152	168	185	203	223	244	268	295
	110	124	138	154	170	187	205	225	247	271	299
	110	124	139	155	171	188	207	227	249	274	303
	111	125	140	156	172	190	209	229	252	277	308

---

[1] Values for ages under 100 are from equation II (in feet), those for over 100 are from equation III
t). Corresponding site index estimation curves are shown in figure 5.

[2] Note that biologically impossible values merely indicate that no height actually observable at
e justifies the indicated estimate of Ĥ100 (Curtis et al. 1974a).

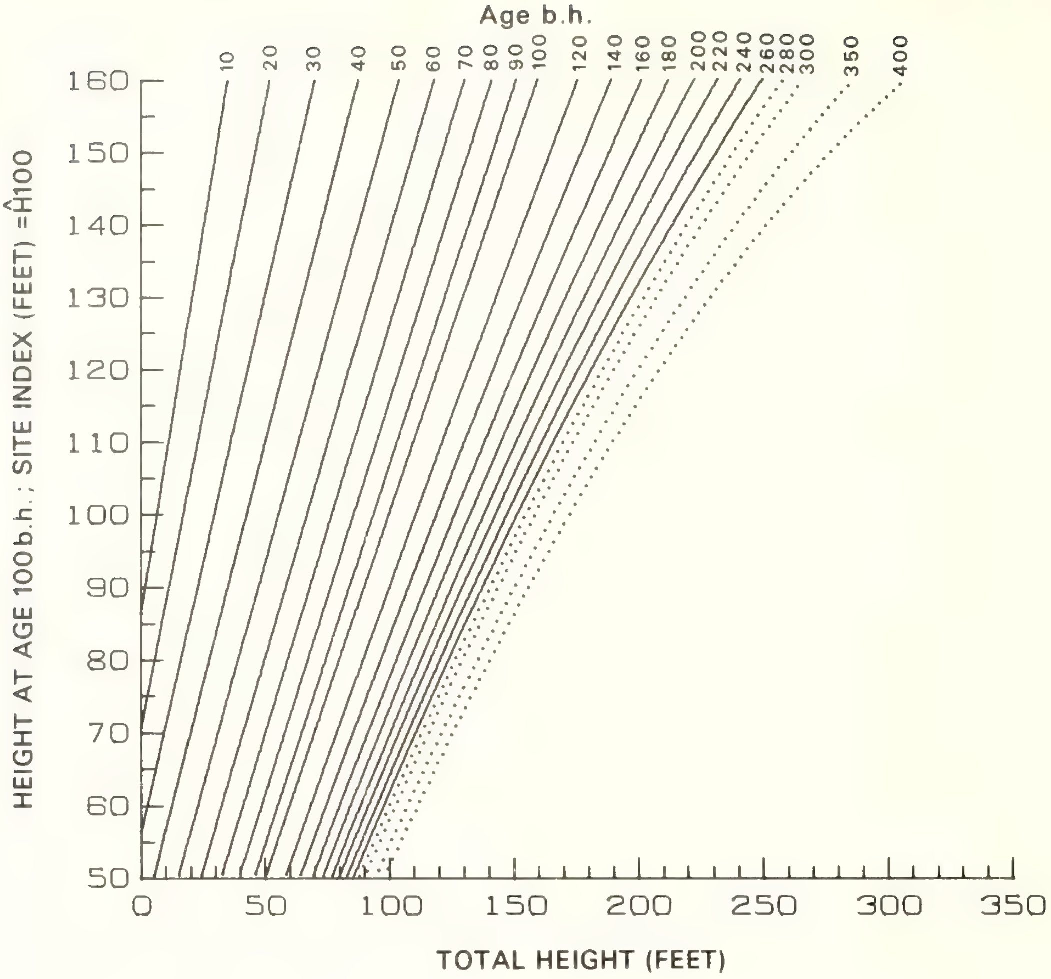


Figure 5.--Site index estimation curves for noble fir. Curves for ages bh less than 100 years correspond to equation II (in feet); those for ages over 100 correspond to equation III (in feet). Note: Use these curves for estimating site index; i.e., for estimating height at 100 years of a tree observed at some other age. These curves may also be used for estimating the probable course of future height growth up to 100 years for dominant trees younger than 100 years. Use these curves when site index is to be expressed in feet.

The resulting equation, after simplification, can be written as:

Equation III, in feet:

$$\hat{H}100 = a + b(H - 4.5) + c(H - 4.5)^2;$$

where,

$a = -62.755 + 672.55(1/x)^{0.5}$,

$b = 0.9484 + 516.49(1/x)^2$,

$c = -0.00144 + 0.1442\ (1/x)$, and

x = age bh.

Standard error of estimate of the transformed variable $w(H100 - H)$ was 0.917

Table 4--*Ages bh and total heights corresponding to indicated estimates of* $H100_m$ *(height at index age 100)*[1]

Age at bh	Height (meters) at index age 100										
	20	23	26	29	32	35	38	41	44	47	50
Years	Meters										
10	[2]-2.9	-1.5	-.1	1.3	2.7	4.2	5.6	7.0	8.5	9.9	11.4
20	-.8	.8	2.6	4.3	6.1	7.8	9.6	11.3	13.1	14.8	16.5
30	1.9	3.9	6.0	8.0	10.0	12.0	14.1	16.1	18.1	20.1	22.2
40	5.1	7.4	9.6	11.9	14.1	16.4	18.7	20.9	23.2	25.4	27.7
50	8.3	10.8	13.2	15.7	18.1	20.5	23.0	25.4	27.8	30.3	32.7
60	11.4	14.0	16.5	19.1	21.7	24.2	26.8	29.4	31.9	34.5	37.1
70	14.1	16.8	19.5	22.1	24.8	27.5	30.2	32.9	35.5	38.2	40.9
80	16.4	19.2	22.0	24.8	27.6	30.4	33.1	35.9	38.7	41.5	44.3
90	18.4	21.3	24.2	27.1	30.0	32.9	35.7	38.6	41.5	44.4	47.3
100	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0
110	21.3	24.4	27.5	30.6	33.7	36.8	39.9	43.1	46.2	49.4	52.5
120	22.5	25.6	28.8	32.0	35.2	38.5	41.7	45.0	48.3	51.6	54.9
130	23.5	26.8	30.0	33.3	36.6	40.0	43.3	46.7	50.1	53.6	57.1
140	24.5	27.8	31.1	34.5	37.9	41.3	44.8	48.3	51.9	55.5	59.1
150	25.4	28.7	32.1	35.6	39.1	42.6	46.2	49.9	53.6	57.3	61.1
160	26.2	29.6	33.1	36.6	40.2	43.8	47.5	51.3	55.1	59.0	63.0
170	26.9	30.4	33.9	37.5	41.2	44.9	48.7	52.6	56.6	60.6	64.7
180	27.6	31.1	34.8	38.4	42.2	46.0	49.9	53.9	58.0	62.2	66.4
190	28.2	31.8	35.5	39.3	43.1	47.0	51.0	55.1	59.3	63.6	68.1
200	28.9	32.5	36.2	40.0	43.9	47.9	52.0	56.3	60.6	65.1	69.7
210	29.4	33.1	36.9	40.8	44.7	48.8	53.0	57.4	61.8	66.4	71.2
220	30.0	33.7	37.5	41.5	45.5	49.7	54.0	58.4	63.0	67.8	72.7
230	30.5	34.2	38.1	42.1	46.2	50.5	54.9	59.4	64.1	69.1	74.2
240	30.9	34.8	38.7	42.8	46.9	51.3	55.7	60.4	65.3	70.3	75.7
250	31.4	35.3	39.2	43.4	47.6	52.0	56.6	61.3	66.3	71.6	77.1
260	31.8	35.7	39.8	43.9	48.2	52.7	57.4	62.3	67.4	72.8	78.5
270	32.2	36.2	40.3	44.5	48.9	53.4	58.2	63.1	68.4	73.9	79.9
280	32.6	36.6	40.7	45.0	49.4	54.1	58.9	64.0	69.4	75.1	81.2
290	33.0	37.0	41.2	45.5	50.0	54.7	59.6	64.8	70.3	76.2	82.6
300	33.4	37.4	41.6	46.0	50.5	55.3	60.3	65.6	71.3	77.4	84.0
310	33.7	37.8	42.0	46.5	51.1	55.9	61.0	66.4	72.2	78.5	85.3
320	34.0	38.2	42.4	46.9	51.6	56.5	61.7	67.2	73.1	79.6	86.7
330	34.3	38.5	42.8	47.3	52.1	57.0	62.3	67.9	74.0	80.7	88.0
340	34.6	38.8	43.2	47.8	52.5	57.6	62.9	68.7	74.9	81.7	89.4
350	34.9	39.2	43.6	48.2	53.0	58.1	63.6	69.4	75.8	82.8	90.8
360	35.2	39.5	43.9	48.5	53.4	58.6	64.1	70.1	76.6	83.9	92.2
370	35.5	39.8	44.2	48.9	53.9	59.1	64.7	70.8	77.5	85.0	93.6
380	35.8	40.1	44.6	49.3	54.3	59.6	65.3	71.5	78.3	86.0	95.1
390	36.0	40.3	44.9	49.6	54.7	60.1	65.9	72.2	79.1	87.1	96.6
400	36.3	40.6	45.2	50.0	55.1	60.5	66.4	72.8	80.0	88.2	98.2

---

[1] Values for ages under 100 are from equation II (in meters); those for over 100 are from equation III (in rs). Corresponding site index estimation curves are shown in figure 6.

[2] Note that biologically impossible values merely indicate that no height actually observable at that age ifies the indicated estimate of $H100_m$ (Curtis et al. 1974a).

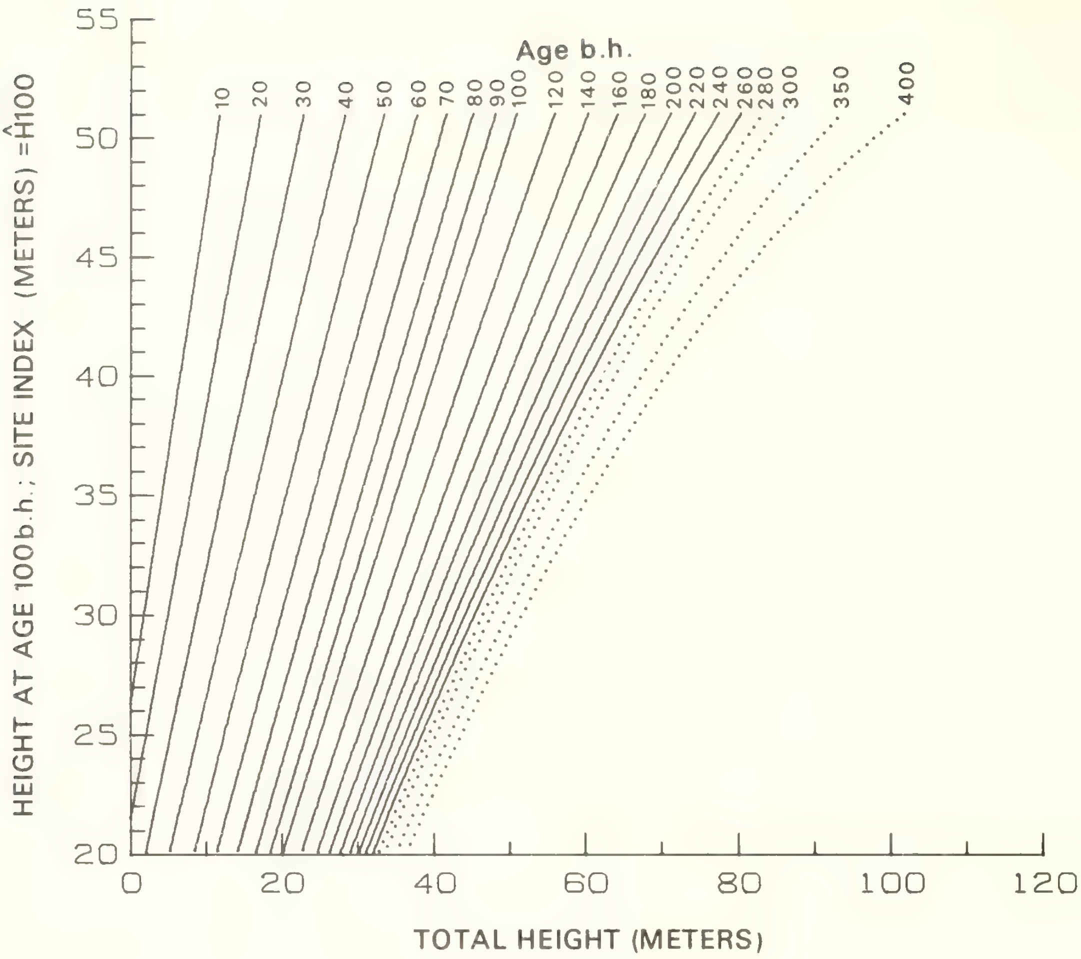


Figure 6.--Site index estimation curves for noble fir. Curves for ages bh less than 100 years correspond to equation II (in meters); those for ages over 100 correspond to equation III (in meters). Note: Use these curves for estimating site index; i.e., for estimating height at 100 years of a tree observed at some other age. These curves may also be used for estimating the probable course of future height growth up to 100 years for dominant trees younger than 100 years. Use these curves when site index is to be expressed in meters.

Corresponding numerical values are given in table 3 and curves in figure 5 for ages bh of 100+ years.

Equation III, in meters:

$$\hat{H}100_m = a + b(H_m - 1.37) + c(H_m - 1.37)^2;$$

where,

$a = -19.128 + 204.99(1/x)^{0.5}$,

$b = 0.9484 + 516.49(1/x)^2$,

$c = -0.00473 + 0.47297(1/x)$, and

$x =$ age bh.

Corresponding numerical values are given in table 4 and curves in figure 6 for ages bh of 100+ years.

Discussion

The index age of 100 years bh was chosen as consistent with precedent, with previous work with associated Douglas-fir (Curtis et al. 1974b), with growth characteristics of the species, and with the relatively long rotations which seem probable in these high-elevation forests.

The height growth equation and corresponding curves obtained by fitting regressions with height as the dependent variable differ from the site index estimation equations and curves obtained by treating attained height at the index age (H100) as the dependent variable. These curves are appropriate for different uses (Curtis et al. 1974a).

HEIGHT GROWTH CURVES

Height growth curves H = f(age, H100) represent average development of trees that actually attained a specified height at index age 100 (H100). They express the pattern of height growth of the tallest dominant trees in relation to age, within even-aged stands. They are the appropriate basis for expressing height development in the construction of yield tables or yield functions representing average development of even-aged stands actually attaining specified heights at index age (site indices).

These noble fir height growth curves (figs. 3 and 4) demonstrate the ability of undamaged trees to maintain height growth to very advanced ages. This striking characteristic has previously been noted in Douglas-fir in these high-elevation forests (Curtis et al. 1974b). Although no corresponding volume growth information is available, such a growth pattern must clearly be associated with a similar sustained increment in volume.

SITE INDEX ESTIMATION CURVES

The site index estimation curves (figs. 5 and 6), obtained by treating H100 as the dependent variable, are more efficient estimators of height at index age than the traditional inverted form of the height growth curves[3/] (when available information consists only of a measured height at some age other than index age). These site index estimation curves are the appropriate basis for estimating height at index age (100 years) of a tree observed at some other age; and also for estimating the probable course of future height growth up to this index age for a tree observed at a present age that is less than the index age.

POSSIBLE BIAS

When growth curves and site index estimation curves are prepared from stem analyses of mature trees, there is no way of evaluating stand conditions in early life, beyond limiting the sample to stands which appear even-aged and then rejecting trees showing a growth pattern suggesting past injury or early suppression. Probably not all the tallest trees were always

---

[3/] For a detailed and complete explanation of the relative efficiency and uses of the traditional height growth curves and these site index estimation curves, see Curtis et al. (1974a).

the tallest in early life. Bias can be introduced by such shifts in relative crown position of sample trees over time (Dahms 1963). Although it seems unlikely that this would materially alter the shape of curves within the range of substantial overlap in tree ages (in this case roughly 100 to 250 years), such unrecognized shifts in crown position could introduce considerable bias at younger ages. Usually only one noble fir tree was selected at each location, so there was no direct means of evaluating the actual importance of such bias. At the few locations where two or more noble fir trees were felled and sectioned, observed shifts in relative crown position were, however, infrequent and minor. Because of the shade intolerance of noble fir, that observation is not unexpected.

APPLICATION OF CURVES

These curves are applicable only to trees growing under essentially even-aged stand conditions.

Each sample tree was chosen as the tallest undamaged dominant on an area of about one-fourth acre (0.1 ha) in stands of mixed species composition. In these old stands, with variable composition and frequent top damage, this is a less consistent definition than in young stands of a single species. Consistency of definition and application is more important than exact adherence to this area standard, and, in the usual older mixed stands, the stand component represented by these curves is best considered as well-distributed undamaged dominants.

To estimate site index for a stand, select a sample of undamaged dominant noble fir well distributed over the area. Exclude trees showing evidence of past damage or early suppression (visible stem damage, abrupt changes in radial growth pattern on increment cores) or differences in age class from surrounding trees. Determine total height and age bh for each sample tree. Use these values and equations II and III, tables 3 and 4, or figures 5 and 6 to estimate H100 for each tree. The mean of these estimates of H100 is the estimated site index of the stand.

The height growth and site index information presented in this paper provides a basis for site classification of Cascade Range forests containing noble fir. That basis is the first step toward development of growth and yield preditions for the complex upper-slope forests of the Pacific Northwes

Literature Cited

Dahms, Walter G.
1963. Corrections for a possible bias in developing site index curves from sectioned tree data. J. For. 61(1):25-27, illus.

Curtis, Robert O., Donald J. DeMars, and Francis R. Herman.
1974a. Which dependent variable in site index-height-age regressions? For. Sci. 20(1):74-87, illus.

Curtis, Robert O., Francis R. Herman, and Donald J. DeMars.
1974b. Height growth and site index estimates for Douglas-fir (*Pseudotsuga menziesii*) in high-elevation forests of the Oregon-Washington Cascades. For. Sci. 20(4):307-316, illus.

DeMars, Donald J., Francis R. Herman, and John F. Bell.
1970. Preliminary site index curves for noble fir from stem analysis data. USDA For. Serv. Res. Note PNW-119, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Heger, L.
1968. A method of constructing site index curves from stem analysis. For. Chron. 44(4):11-15.

Herman, Francis R., Donald J. DeMars, and Robert F. Woollard.
1975. Field and computer techniques for stem analysis of coniferous forest trees. USDA For. Serv. Res. Pap. PNW-194, 51 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

GPO [illegible]

Herman, Francis R., Robert O. Curtis, and Donald J. DeMars.
1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. USDA For. Serv. Res. Pap. PNW-243, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Height growth and site index estimation equations with corresponding curves and tables for noble fir in the Cascade Range between McKenzie Pass in Oregon and Stevens Pass in Washington are presented in U.S. measurements and in metric equivalents.

KEYWORDS: Site index -)stand height/age, increment (height), altitude (-site, noble fir, *Abies procera*, Oregon (Cascade Range), Washington (Cascade Range).

Herman, Francis R., Robert O. Curtis, and Donald J. DeMars.
1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. USDA For. Serv. Res. Pap. PNW-243, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Height growth and site index estimation equations with corresponding curves and tables for noble fir in the Cascade Range between McKenzie Pass in Oregon and Stevens Pass in Washington are presented in U.S. measurements and in metric equivalents.

KEYWORDS: Site index -)stand height/age, increment (height), altitude (-site, noble fir, *Abies procera*, Oregon (Cascade Range), Washington (Cascade Range).

Herman, Francis R., Robert O. Curtis, and Donald J. DeMars.
1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. USDA For. Serv. Res. Pap. PNW-243, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Height growth and site index estimation equations with corresponding curves and tables for noble fir in the Cascade Range between McKenzie Pass in Oregon and Stevens Pass in Washington are presented in U.S. measurements and in metric equivalents.

KEYWORDS: Site index -)stand height/age, increment (height), altitude (-site, noble fir, *Abies procera*, Oregon (Cascade Range), Washington (Cascade Range).

Herman, Francis R., Robert O. Curtis, and Donald J. DeMars.
1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. USDA For. Serv. Res. Pap. PNW-243, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Height growth and site index estimation equations with corresponding curves and tables for noble fir in the Cascade Range between McKenzie Pass in Oregon and Stevens Pass in Washington are presented in U.S. measurements and in metric equivalents.

KEYWORDS: Site index -)stand height/age, increment (height), altitude (-site, noble fir, *Abies procera*, Oregon (Cascade Range), Washington (Cascade Range).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: *Pacific Northwest Forest and Range*
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives – as directed by Congress – to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

USDA FOREST SERVICE RESEARCH PAPER PNW-244

A CASE STUDY of a DOUGLAS-FIR TUSSOCK MOTH OUTBREAK and STAND CONDITIONS 10 YEARS LATER

OV 13 1976
TECH. & AGR. DIV.

BOYD E. WICKMAN

ITEM

PACIFIC NORTHWEST FOREST and RANGE EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT of AGRICULTURE
PORTLAND, OREGON

- E R R A T A -

This is a corrected copy of figure 6, page 11, for USDA For. Serv. Res. Pap. PSW-241, "A Case Study of a Douglas-fir Tussock Moth Outbreak and Stand Conditions 10 Years Later," by Boyd E. Wickman.

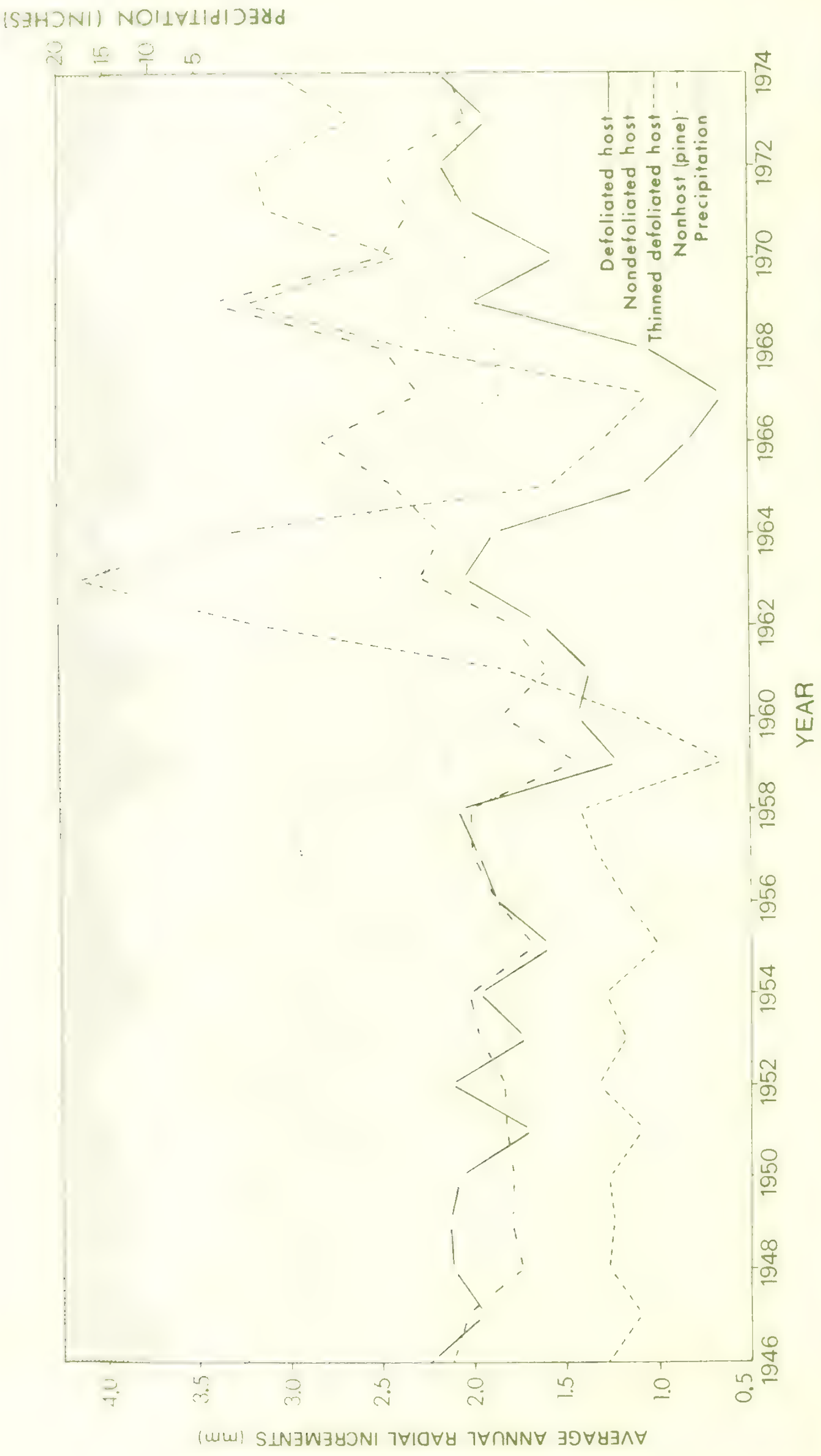


Figure 6.—Average annual radial increment at d.b.h. comparison of hosts and nonhosts, Stowe Reservoir, and annual precipitation, Cedarville.

Case Study of a Douglas-fir Tussock Moth Outbreak and Stand Conditions 10 Years Later

ence Abstract

man, Boyd E.
)78. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. USDA For. Serv. Res. Pap. PNW-244, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

e damage occurring immediately after an outbreak of
las-fir tussock moth, *Orgyia Pseudotsugata* McD., and stand
tions 10 years later are described. Because of increased radial
h and ingrowth in the 10-year postoutbreak period, good
nce indicates that tree damage caused by the tussock moth
not be as severe in the overall stand dynamics as previously
ed. The insect probably plays a key role as a phytophagous
tor of primary production in some second-growth white fir
s in California and elsewhere.

VORDS: Insect damage (-forest, Douglas-fir tussock moth, *Orgyia Pseudotsugata*

ARCH SUMMARY
rch Paper PNW-244

early summer 1964, campers at the
Reservoir campground were noticing
mplaining about hairy little caterpillars
ing on their picnic tables and food.
ground garbage collectors a few weeks
complained that the abundant cater-
gave them a rash when they dropped
their bare arms or necks. Local Forest
e personnel investigated and found de-
on on many fir trees. They immediately
ted help from regional office entomolo-
who identified the hairy little cater-
(now quite a bit larger) as Douglas-fir tussock moth larvae, which were very rapidly devouring most of the foliage on white firs near the campground. In an emergency effort to control the insects in and around the campground, 200 acres were sprayed with malathion on August 2, 1964, with absolutely no effect on the population. By then the entire Stowe Reservoir basin of 450 acres had turned reddish brown from the feeding activity. An outbreak was obviously in progress—the results of that outbreak and what followed are the subjects of this paper.

Introduction

1964-65, the Douglas-fir tussock moth, *a pseudotsugata* McD., caused heavy ation of white fir, *Abies concolor* l. and Glend.) Lindl., over thousands of of timber stands in northeastern Cali- a. Large patches of saplings and pole-size were completely stripped of needles. By ummer 1964, tree mortality was occur- on heavily defoliated areas in the largest ded outbreak in California: 76,000 acres e infestation centers. Stowe Reservoir one of those infestation centers and, ugh the smallest, was the most intensely ed in the entire outbreak.[1]

June and July 1965, 57,079 acres ding 2,098 acres around Stowe Reservoir aerially treated with 3/4 lb DDT in 1 gal el oil per acre. The combined effects of nsecticide, a natural virus, and other al enemies halted the outbreak. But tree ge of varying degrees was obvious over a area.

cause the infested area at Stowe Reservoir mall yet typical of a normal large out- in northeastern California, several stud- ere undertaken there on the development g mass sampling (Luck and Dahlsten) and aerial photography techniques for ing tree damage (Wert and Wickman 1970). The area was also visited 5 after the outbreak to assess effects on mpground (Wickman and Renton 1975) o make some measurements of tree lity and growth. In 1975, the area was d for tree mortality, stand conditions, ree growth in an attempt to duplicate round measurements of a 1967 aerial graphy study (Wert and Wickman . The objective of this paper was to see kind of stand mortality, tree growth, growth prevailed on a seriously dam- utbreak area 10 years later. The effects of the outbreak have also been reported in summary fashion (Wert and Wickman 1970, Wickman et al. 1973). This paper describes the stand conditions before the outbreak, damage immediately after the outbreak, and conditions 10 years later. Because of the intensive research efforts in the area to date and its maintenance by the Modoc National Forest in an undisturbed state, I hope that additional studies will be carried out in future years.

Study Area

Stowe Reservoir (fig. 1) is 1 mile (1.6 km) east of Cedar Pass on Highway 299 in the Warner Mountains of Modoc County, California. The Warner Mountains are an isolated range lying north-south about 100 miles (160 km) long. The south portion, about 60 miles (97 km), is in California just east of Alturas; the remainder extends into Oregon. The range is in the form of a tilted block, with a steep slope along the fault on the east side. Elevations over 9,000 ft (2 750 m) occur, but the crest of the range averages 7,000 to 8,000 ft (2 220 to 2 450 m). Cedar Pass is the lowest pass and bisects the range in the middle of the California portion. The west flanks of the Warner Mountains are heavily timbered with pine and fir. Stowe Reservoir is on the drier, east flank where timber grows in scattered patches along with sagebrush and juniper.

The 1964-65 tussock moth infestation occurred on 450 acres (182 ha) in a moderately sloping basin with mainly south and east exposures. The elevation ranges from 5,600 to 6,200 ft (1 700 to 1 900 m) with higher elevations and rocky escarpments immediately to the north and west. The second-growth stand is predominantly white fir with a scattering of ponderosa pine, *Pinus ponderosa* Laws., Washoe pine, *P. washoensis* Mason and Stockwell, and western juniper, *Juniperus occidentalis* Hook., at the lower elevations and southern exposures.

---

[1] ublished mimeographed report, "Douglas-fir tussock festations in northern California, 1964," by John R. USDA For. Serv. Reg. 5, Div. Timber Manage., San o, Calif. December 14, 1964.

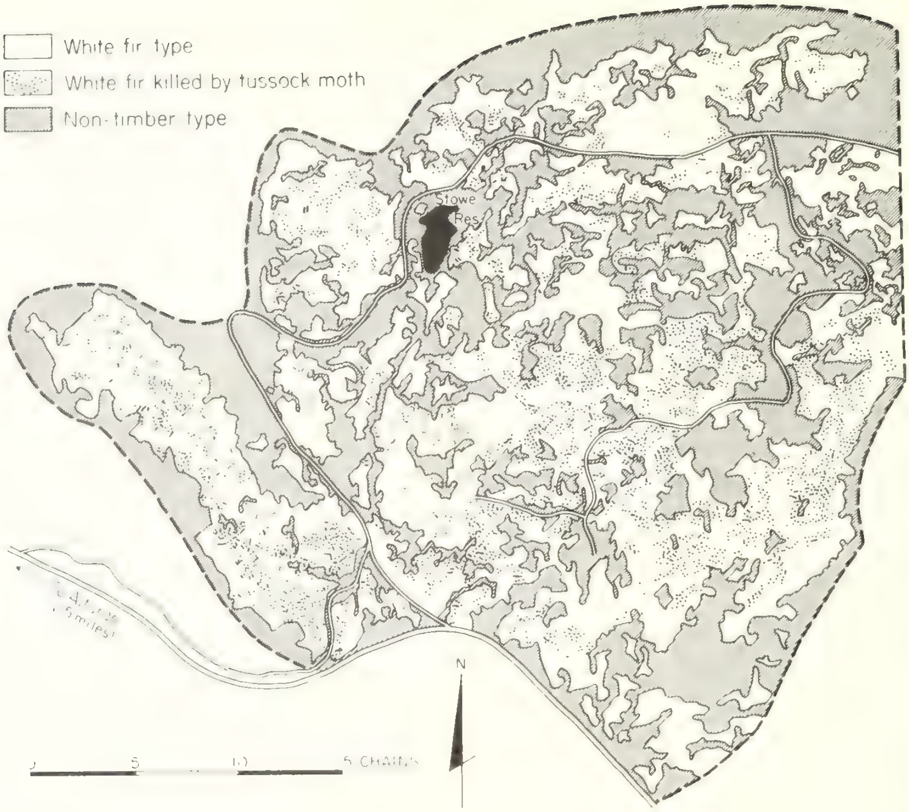


Figure 1.—Location and area of white fir type killed by defoliation from the Douglas-fir tussock moth at Stowe Reservoir. The map was produced from the 1:8,000-scale color photography.

The original stand was heavily logged about the turn of the century and the stumps show that a pine stand of large trees (36- to 40-in d.b.h.) covered all but the upper elevations. It was logged a second time for fir overstory in all but the campground area in 1954. No fires have burned in the stand for at least 50 years and probably none since the turn of the century. White fir is now the predominant tree species, growing as scattered patches of saplings, poles, and young sawtimber throughout the basin.

Methods

Numerous examinations have been made of the outbreak since 1967 to obtain various bits of information, for example damage to the campground (Wickman and Renton 1975 but only the major study efforts will b recorded here.

In 1967, as part of an aerial photograph study, a crew systematically sampled the are by examining conditions on 1/50th-acr (0.008-ha) circular plots, established at chain intervals along cruise lines 5 chair apart (Wert and Wickman 1970). Small-sca (1:8,000 ft) aerial photographs were used t determine cruise lines. Large — scal (1:1,500 ft) aerial photo coverage and dat from the plots provided an estimate of pr outbreak stand conditions and total white f damage in the area. A 1.5-percent sample c the area or 5.7 acres (2.3 ha) of plots wer established to obtain a coefficient of variatio

5 percent of the number of green and trees. On each plot, the following were ded: d.b.h. of all trees 1-in and larger; species; crown condition (alive, dead, normal, and length of top-kill, if pres- year and cause of death; and white fir eration (alive and dead). Standard ne tables were used to compute volume een and dead trees.

1975, using the same small-scale aerial ographs to establish cruise line locations, epeated the examinations. We tried to cate the techniques used in 1967 as y as possible to determine stand condi- 10 years later. One difference occurred, ver, because of an error in the Wert and nan (1970) publication. That publica- states that 1/40th-acre (0.01-ha) plots used, but the original study plan and containing data calculations state the ize as 1/50th acre. The plot size was set 40th acre, as stated in the publication. onsequently carried out the 1975 cruise slightly larger plots, ending with a larger e: 279 plots or 7 acres (2.8 ha) of e. The only effect of increased plot size l be to increase precision of the later e.

also took radial-growth measurements 975 (additional samples were taken in) to determine stand growth and changes owth patterns. Two increment cores were at breast height on each dominant or minant tree nearest the plot center on third plot. Cores were also taken from on about every eighth plot, from non- ated white fir 0.4 km south of the ay, and defoliated white fir in two plots ed in 1960.

ne information on the level of tree lity in the patches of severe defoliation red through the outbreak was obtained 70. A 100-percent cruise was made of tches of tree mortality.

---

v filed at Rocky Mt. For. and Range Exp. Stn., Fort Colo.

In 1969 we destructively sampled five white fir with known 1965 defoliation levels by cutting discs at breast height, midcrown, and 17 internodes from the terminal. My inferences are restricted to this specific geographic locality; however, within it, statistical tests (regression analysis and t-tests) were applied to certain classes of trees. Stand characteristics were compared by stratifying individual 1/50th-acre plots into stand classifications. When characteristics of individual trees are examined statistically, I am assuming independent random sampling of trees even though trees occur in clusters by plots.

Results

A summary of the green-stand statistics is given in table 1 for 1964, preoutbreak; 1967, 2 years postoutbreak; and 1975, 10 years postoutbreak. Calculations of damage and recovery that follow are based on these figures.

TREE MORTALITY

Most of the mortality was caused by the effects of defoliation alone (table 2). Little mortality was caused by fir engraver beetle (*Scolytus ventralis* Lec.) in weakened trees. And most of the mortality occurred in 1964-65 and then tapered off the next 2 years. During the 1975 cruise, we attempted to back-date mortality to see if we could estimate losses from tussock moth after 10 years and also to see if losses were continuing. Tree death can be back-dated fairly accurately for about 2 years; so table 3 presents reliable tree mortality data by year and cause for 1973 to 1975. Cause and amount of outbreak mortality is difficult to identify accurately after 10 years, but apparently little bark beetle activity continued after 1967. In 1973 a general increase of this type of tree mortality occurred in white fir throughout the Warner Mountains.

Table 1—Green-stand white fir and ponderosa pine (larger than 1-inch d.b.h.) at Stowe Reservoir, 1964-1975

Year	Per acre						
	Living trees		Basal area		Volume[a]		D.b.h.
	No.	S.E.	F^2	S.E.	Fbm	S.E.[b]	average (in)
White fir							
1964	331	19	193.2	10.8	13,101	1,077	8.8
1967	220	13	142.0	8.7	9,857	823	9.3
1975	240	16	132.4	7.6	11,013	912	7.7
Ponderosa pine							
1964	19	3	19.5	2.9	1,482	235	12.9
1967	18	3	18.6	2.8	1,422	231	12.8
1975	17	3	16.0	2.6	1,424	290	11.2

[a] International 1/4-in rule—trees 10.0-in d.b.h. and larger to a 6-in top diameter inside ba

[b] Standard error of mean determined from individual-plot data.

Table 2—White fir mortality by year and cause, Stowe Reservoir, 1964-67, (based on 1,889 trees alive in 1964)

Year	Tussock moth		Bark beetle		Tussock moth & bark beetle[a]		Other	
	No.	%	No.	%	No.	%	No.	%
Pre-1964	0	0	0	0	0	0	4	0.2
1964[b]	528	28.0	2	0.9	0	0	1	0.4
1965			15				7	
1966	12	0.6	48	2.5	4	0.2	4	0.2
1967	0	0	7	0.4	3	0.2	2	0.1
Total	540	28.6	72	3.8	7	0.4	18	1.0

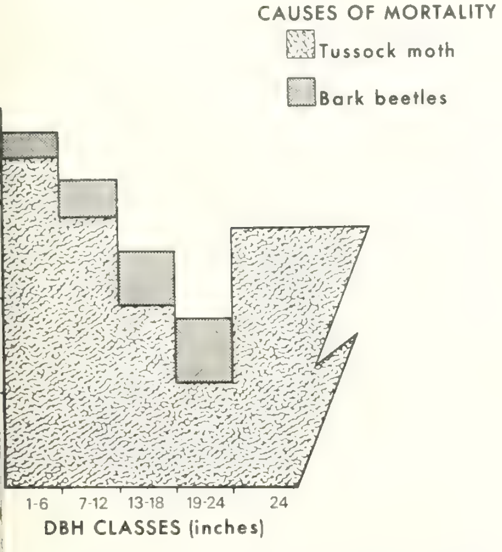
[a] Not certain which killed the tree.

[b] Not certain of year of death.

Table 3—White fir mortality by year and cause, Stowe Reservoir, 1973-75 (based on 1,725 trees living in 1973)

Tussock moth		Bark beetle		Other	
No.	%	No.	%	No.	%
0	0	16	0.9	1	0.1
0	0	25	1.5	5	0.3
0	0	3	0.2	1	0.1
0	0	44	2.6	7	0.5

ite fir mortality was stratified by diame-
asses, based on the 1967 data (fig. 2).
of the loss caused by tussock moth
red in the 1- to 6-in d.b.h. class, but the
amount of mortality caused by bark
steadily increased up to the 19- to
d.b.h. class. Trees larger than 24-in
suffered no loss from bark beetles on
ots.



2.—Percent mortality of white fir by
l.b.h. classes, Stowe Reservoir, 1967.

summary of stand statistics from the
cruise is given in table 4. From these
we calculated that 28.6 percent of the
(number of trees) and 20.6 percent of
and volume were killed by the tussock
in this heavily defoliated outbreak area.
bark beetle mortality was added, about 32 percent of the stand volume was killed. Tree mortality was also summarized (table 5) for advanced reproduction (trees below 1 inch in diameter but more than 10 years old) and recent regeneration (trees less than 10 years old). This information was compared for the 1967 and 1975 cruises to show the amount of mortality caused by tussock moth and amount of postoutbreak regeneration and ingrowth for these size classes. Mortality has been high among advanced reproduction since 1967, even without defoliation. Most of these trees were suppressed and over-topped so the recent high mortality was probably caused by competition. From the difference between 1967 losses (29 percent) and 1975 losses (20 percent), I infer that only 9-percent mortality was caused by tussock moth in this class. In any case, in-growth of this size class has resulted in more trees per acre in 1975 than were present before the outbreak.

Regeneration-sized trees apparently suffered 34-percent mortality from tussock moth, but by 1975 the total number of white fir regeneration-size trees was equal to preoutbreak levels. Most of this regeneration was 6 to 9 years old, indicating a rapid reestablishment of white fir seedlings. The largest concentrations of regeneration were found in the patches of 1965 tree mortality.

PATCHES OF TREE MORTALITY

The data from the five patches of severe tree mortality cruised in 1970 are summarized

Table 4—Summary of 1967 white fir stand conditions per acre

Item	Mean/acre	S.E.
Number of live trees	220.4	13.1
Basal area	142.0	8.7
Number of dead trees	111.8	10.6
Number killed by tussock moth	94.9	9.8
Volume[a] live	9,857	823
Volume[a] dead (includes bark beetle caused mortality)	3,347	567
Volume[a] killed by tussock moth	2,688	523

[a]Board feet, Scribner International Rule.

Table 5—Survival and mortality of white fir regeneration by year and size (age) class

Year	Trees per acre											
	Advance reproduction						Regeneration					
	Living			Dead			Living			Dead		
	No.	S.E.	%	No.	S.E.	%	No.	S.E.	%	No.	S.E.	%
1967	7.20	1.85	70.6	3.00	1.40	29.4	85.61	9.85	65.9	44.21	6.75	34
1975	43.36	4.84	79.8	10.96	2.84	20.2	129.75	25.33	98.7	1.72	.93	1

1967—44% of 1/50th-acre plots have regeneration.
1975—36% of 1/40th-acre plots have regeneration.

Table 6—Sample of five patches of white fir severely damaged by Douglas-fir tussock moth, 1964-1967

Patch no.	Size (acres)	Dead trees/acre (no.)	Live trees/acre (no.)	Total trees/acre (no.)	Mortality/acre (percent)
1	2.5	305	85	390	78.2
2	5.75	369	24	393	93.9
3	1.0	224	58	282	79.4
4	3.5	259	55	314	82.5
5	4.0	319	61	380	83.9
Total	16.75	1,476	283	1,759	
$\overline{x}$	3.4	295.2	56.6	351.8	83.9
S.E.		25.0	9.7		

Table 7—Top-kill determined during the 1967 cruise, by percent of top-kill in various d.b.h. classes

	Percent of crown top-killed				
	1-10	> 10	Total	Other top-kill	
	Percent				
	5.3	0.4	5.7	0	
	10.1	6.2	16.3	2.2	
	6.1	12.5	18.6	1.0	
	5.6	13.9	19.5	0	
	0	0	0	0	
es	7.3	5.1	12.4	1.0	13.4 total

le 6. The average size of these patches .4 acres, and they contained 295 dead per acre (83.9 percent of the stand). All es of tree mortality of 1 acre or larger in utbreak were delineated on the aerial s and measured with a dot grid. From neasurement, I estimated that this type nage occurred on about 8 percent of the 37 acres of the 450 acres mapped as eak. When calculated on the basis of 270 cres of white fir type within the 450 acres, then patches of tree mortality red on 14 percent of the timbered area.

TOP-KILL

1967 only three classes of top-kill were to record this type of damage. They -10 percent of the crown killed, greater than 10 percent, and older or top-kill unrelated to tussock moth. Top-kill data are summarized in table 7. The greatest amount of top-kill (7.3 percent) occurred in the 1 to 10 percent of the crown category, followed by those trees with greater than 10 percent of the crown top-killed (5.1 percent). Total top-kill attributed to defoliation was 12.4 percent, similar to the 12 percent found in an earlier California outbreak (Wickman 1963), but less than found in the Blue Mountains outbreak (Wickman 1978).

Top-kill was also tallied during the 1975 cruise, but six classes were used. They were: leader-only (not attributed to tussock moth at this late date); 1 to 10 percent of the crown killed; 11 to 25 percent; 26 to 50 percent; greater than 50 percent; and other older top-kill (fig. 3). Perhaps only a portion of the

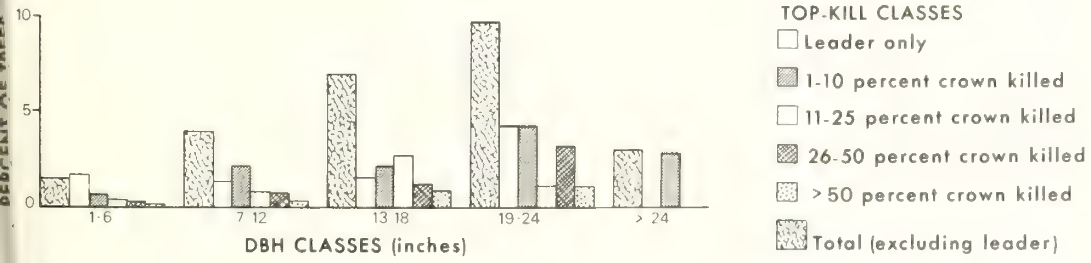


Figure 3.—Percent top-kill of white fir by d.b.h. classes for Stowe Reservoir, 1975.

top-kill was outbreak related, but we wanted to see if an increase of top-kill incidence or severity might be attributed to 1964-65 defoliation. The 1975 data were combined into the three classes used for 1967 data, with leader-only top-kill included in the "other" category not caused by tussock moth (table 8).

An interesting finding is that total top-kill in the stand dropped from 13.4 percent in 1967 to 7.0 percent in 1975, and this included leader-only damage (1.6 percent) which we did not tally in 1967. The probable reason for the decline in top-kill was that more top-killed trees died during the interval from 1967 to 1975 than non-top-killed trees. Some evidence suggests that top-killed trees are more susceptible to mortality by bark beetles (Wickman 1963 and 1978). No explanation has been found for the leader-only damage, but light-to-moderate defoliation by Modoc budworm (*Choristoneura viridis* Freeman) occurred in the area in 1974 and 1975.

FOLIAGE CONDITION

Foliage condition categorized subjectively as being "normal" or "thin" was estimated for each tree for both cruises. We did this because we did not have any defoliati estimates for individual trees and thought th the thin-foliage trees were probably the mo severely defoliated in 1964 and 1965. check of this condition 10 years later in 19 could give some indication of foliage r covery. These data were summarized for bo cruises by diameter classes to see if son effect was related to tree size (table 9).

The data suggest several relationships. Fir most of the thin-foliage trees in 1967 o curred in the 1- to 6-in and 7- to 12-in d.b. classes, indicating either more severe defoli tion in those classes or slower foliage recove 2 years after the outbreak. Second, 2 yea after the outbreak over half the trees lo normal in foliage complement. And third, 1 years after the outbreak 98 percent of t trees appear to have normal foliage compl ments with most of the thin-foliage tre remaining in the 1- to 6-in d.b.h. class. Son of these trees may have been categorized th because they were suppressed understory.

GROWTH

Growth was measured after the outbre by both destructive sampling and increme cores. The analysis presented here can

Table 8—Top-kill determined during the 1975 cruise, by percent of top-kill in the various d.b.h. classes

D.b.h. class	Percent of crown top-killed				
	1-10	> 10	Total	Other top-kill	
Inches			Percent		
0-6	0.6	0.8	1.4	3.1	
7-12	2.1	1.8	3.9	2.9	
13-18	2.1	4.8	6.9	1.9	
19-24	4.3	5.4	9.7	10.8	
> 24	0	3.0	3.0	5.9	
All trees	1.4	1.8	3.2	3.8	7.0 tota

Table 9—Foliage condition of white fir by d.b.h. class 1967 and 1975

l.	Foliage condition			
	Normal		Thin	
	No.	%	No.	%
	225	48	243	52
2	245	49	251	51
-18	157	71	64	29
-24	51	86	8	14
24	8	100	0	0
tal	686	55	566	45
	836	97	22	3
2	433	99	4	1
-18	255	100	0	0
-24	83	100	0	0
24	32	100	0	0
tal	1,639	98	26	2

en down into immediate, short-term pat- of growth reduction and 10-year post- eak effects.

Short-term patterns of reduction (im- ate postoutbreak).—In early spring 1965, trees were given defoliation estimates, the scheme of percent of crown lengths y defoliated, reported for the Blue tains outbreak (Wickman 1978). In , five of these trees were felled and uctively sampled with a disk cut at breast t, midcrown, and about 17 internodes the terminal. The defoliation levels for tree were: one tree, 50-percent, and four 75-percent defoliated. Figure 4 shows adial growth averages for these heavily ated trees. They all showed some h reduction starting in 1964, a drastic tion for the years 1965-67, and recovery eoutbreak growth by 1969. Top and own growth was reduced more than at

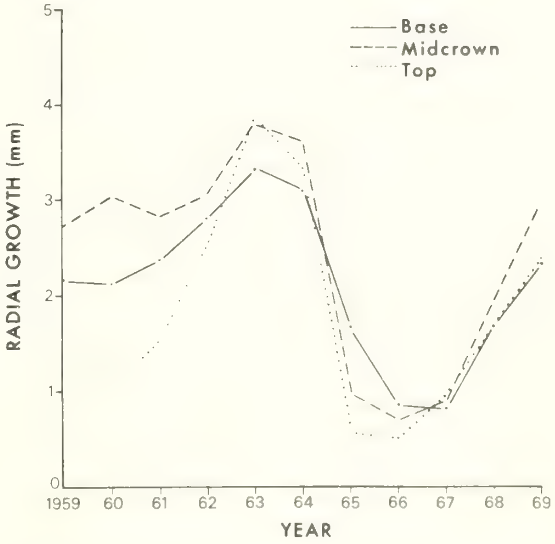


Figure 4.—Average radial growth at base, midcrown, and top for five heavily defoliated white fir, Stowe Reservoir.

the base of trees for 2 years following defoliation. Height growth was also measured on seven additional small trees in heavy defoliation class (50-percent or more defoliated) and seven small trees in the light class (less than 50-percent defoliated). These measurements are shown in figure 5 and follow a pattern similar to radial growth except growth reduction started in 1964 at a pronounced rate and recovery was a year earlier than for radial growth.

The data presented are based on such small samples that it is useful only as an illustration of patterns of growth reduction immediately after defoliation. These patterns are similar to those studied previously (Wickman 1963).

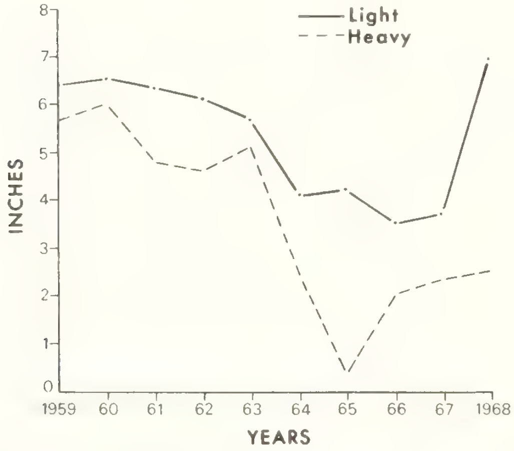


Figure 5.—Average annual height growth for 12 heavily and 7 lightly defoliated white fir, Stowe Reservoir.

2. Ten-year postoutbreak growth patterns.— Growth patterns for the 10-year postoutbreak period were obtained from the following sets of trees: defoliated white fir on the plots, 116 trees; nonhost pine on the plots, 36 trees; defoliated white fir from two plots thinned in 1960, 35 trees—thinned areas were 1.2 and 0.6 acres (.49 ha and .24 ha) and spacing was irregular, but averaged 25 by 25 ft (7.6 m); and nondefoliated white fir, 35 trees. Average radial growth for the period 1946-1974 from each of the four sets of trees is shown in figure 6. The annual precipitation from th station in Cedarville, California, about miles (24 km) east is plotted at the top of th figure. The normal 13 inches (33 cm) per ye is the average from 1940 to 1971. The valu for 1956 and 1957 were estimated, because unavailable data, from values at Altur California, the next closest station.

Data on the nondefoliated white fir and th pine trees in figure 6, show that the sam yearly growth responses are exhibited but th amplitude of the trends are different. Th radial growth trend of the nondefoliat white fir is toward a gradual decline. Th nonhost, ponderosa pine, exhibits increas growth from 1964 to 1969. In part, th increased growth during this period might explained by the natural thinning effect a increased nutrient and water supply duri and immediately after the tussock mo outbreak. The trends change in 1969 wh the pine begins to decrease; the nondefoliat fir decreases slightly and then remains stat

The growth trends of the defoliated wh fir and the defoliated, thinned white exhibit patterns similar to the first two se but only until 1960. The stand representi the thinned host was thinned during 196 and it expressed an unusually high grow response peak in 1963. This peak was simi to that found by Seidel (1977) in suppress grand fir released by killing the overstc lodgepole pine. Growth reduction resulti from defoliation in 1964-65 was similar both thinned and unthinned white fir. Po outbreak growth in thinned plots, howev has been at a higher level than in unthinn white fir.

The depression of growth for all trees 1959, 1961, 1973 appears related to preci tation deficiencies during those periods. T subnormal precipitation from 1965 to 1967 of particular interest because it confounds th effects of defoliation on growth reductio Defoliation obviously depressed growth 1965 and 1966, but the 1967 reducti

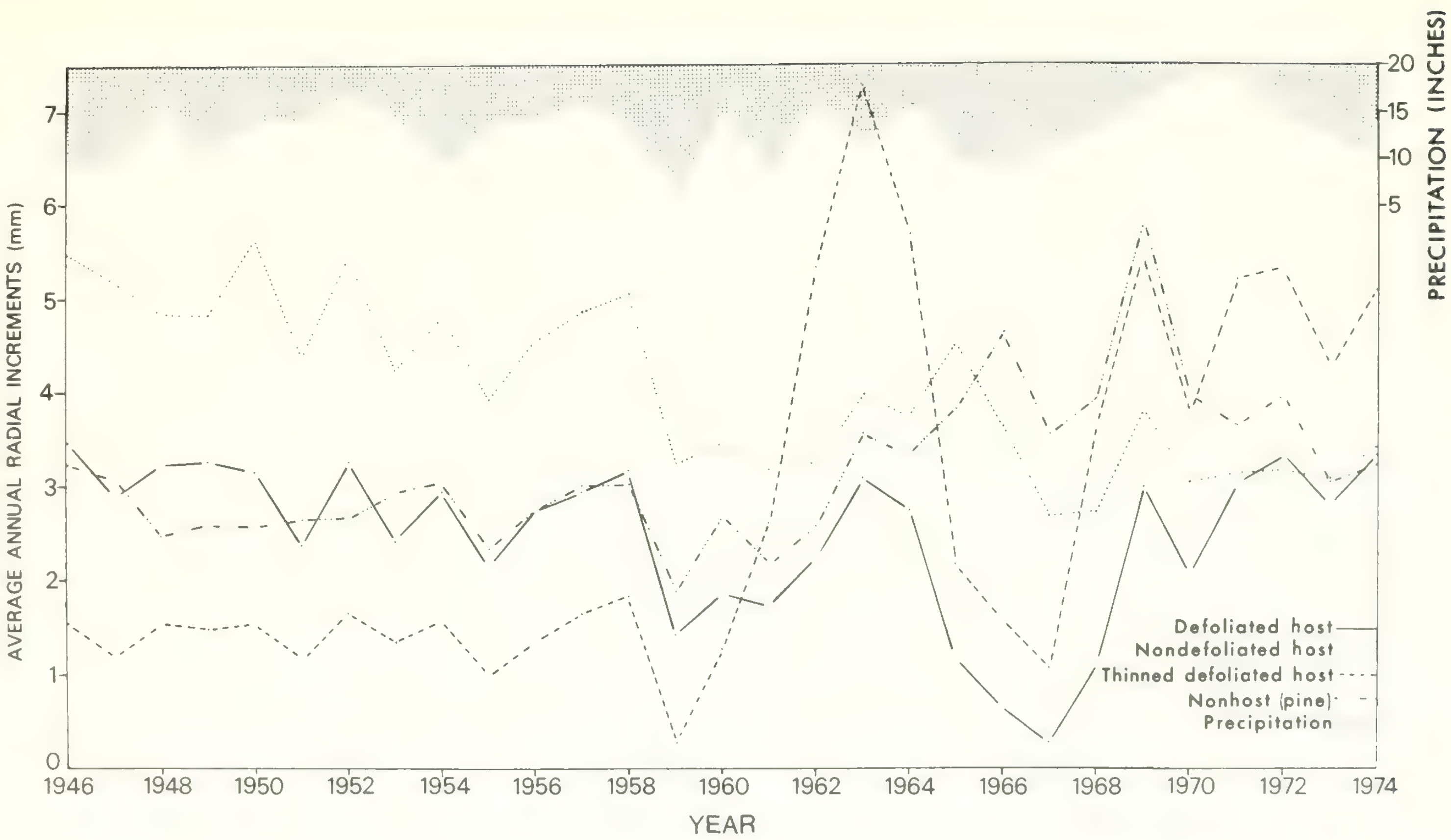


Figure 6.—Average annual radial increment at d.b.h. comparison of hosts and nonhosts, Stowe Reservoir, and annual precipitation, Cedarville.

probably would not have been as severe or recovery might have occurred a year earlier without several years of subnormal precipitation during the critical, postoutbreak recovery period. This points out the complexities in assessing the effects of defoliation on growth and the fallacy of assigning all growth reduction in the defoliated trees to the tussock moth outbreak.

The growth depression in 1970 for all trees is an unexplained anomaly, because it occurred during a period of above-average precipitation. It could have been related to effects of combinations of temperature and precipitation occurring in one or several seasons of the year. It does indicate that tree-growth patterns are complex and often unexplainable because we lack information on the interrelationships of tree physiology with environmental factors in a given locality and time.

Some comparisons were made of average radial growth for the four classes of trees during 6 preoutbreak years of 1959-1964, the 4 outbreak and immediate postoutbreak years of 1965-1968, and 6 postoutbreak years of 1969-1974. Each of the periods has 2 years of depressed growth from environmental effects, and the thinned host has the additional effect of mechanical reduction of stand density in 1960. Paired t-tests were then made to compare growth within each of the four tree classes during these periods.

Growth of defoliated host was significantly reduced (at the .01 level) during and immediately after the outbreak (1965-68) compared to growth in the preoutbreak and postoutbreak periods (table 10). The surprising growth relation for defoliated host is that of the 6-year postoutbreak period. Even in this short time, defoliated-host growth is significantly greater (at the .01 level) than during a similar preoutbreak period. Nondefoliated host shows no significant growth differences among all three periods indicating that environmental effects were not unduly affecting growth in any one period. The thinn defoliated host was similar to the defoliat host except that preoutbreak growth v significantly higher (at the .05 level) th postoutbreak growth. This was probably cause of very high growth in 1962 and 19 as an immediate response to mechani thinning.

The nonhost (pine) growth was sign cantly greater (at the .01 level) during outbreak and postoutbreak periods compa to the preoutbreak period.

Another comparison of growth rates us regression analysis was conducted to t whether a linear relation exists between p and postoutbreak growth and whether relations differ among classes. The relations preoutbreak (1959-1964) to postoutbre growth (1969-1974) were determined fr individual trees, sampled as clusters on plots, for each of the four classes (fig. 7a- The results of that analysis follow:

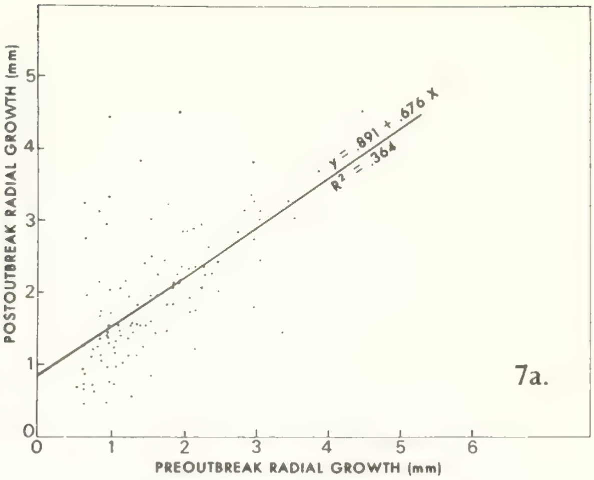
	R^2	F-value	Sign can
Defoliated host	.36	65.20	.0
Nondefoliated host	.84	176.80	.0
Nonhost (pine)	.59	49.36	.0
Thinned, defoliated host	.06	1.99	N.S

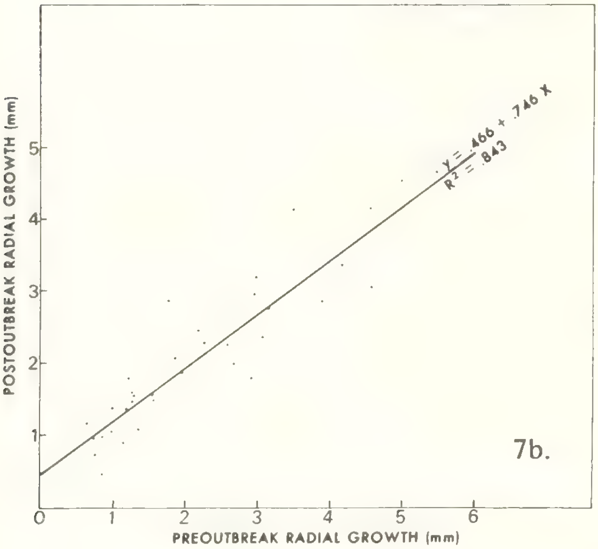
The slopes and intercepts of the signific regression lines were compared using an an sis of covariance (Snedecor and Coch 1967) to determine if the classes had differ relations. In comparing these regression li in pairs, individual nonorthogonal contr are used. Because of the exploratory natur this study, these comparisons were conside adequate. Figure 7e presents the regress lines for the four classes of trees. Using F-test for difference between regression c ficients, the slopes of defoliated host, n defoliated host, and nonhost were all fo to be similar. This indicates that gro relations were similar for the three clas

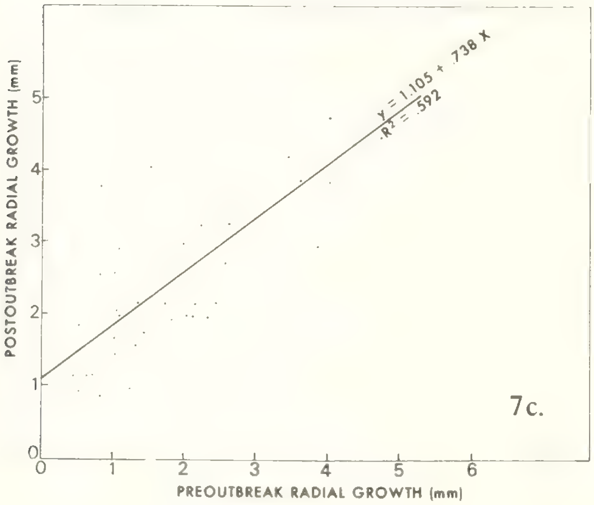
Table 10—Comparisons of average growth in four tree classes during preoutbreak, outbreak, and postoutbreak periods using paired t-tests

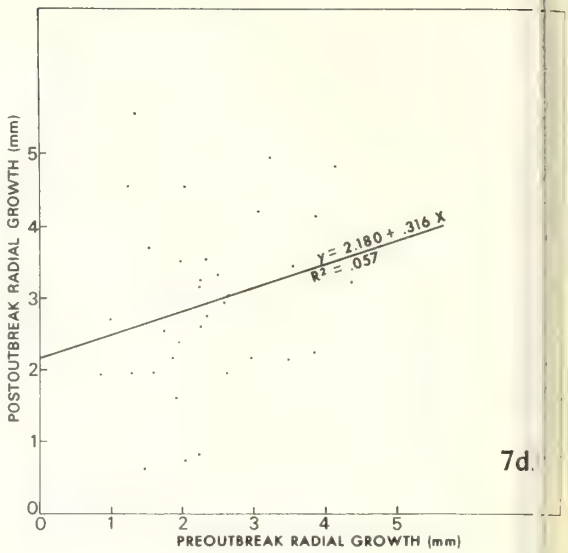
ee class	Means of radial growth			
	1946-1958	1959-1964	1965-1968	1969-1974
foliated host	1.961	1.594	0.908	1.968
ndefoliated host	2.927	2.242	2.197	2.138
inned, defoliated host	1.222	2.380	1.569	2.932
nhost (pine)	1.890	1.853	2.493	2.472

	Growth periods	
	Preoutbreak (1959-1964) with outbreak (1965-1968)	
	T-value	Significance
foliated host	12.173	.01
ndefoliated host	.665	N.S.
inned, defoliated host	6.219	.01
nhost	6.477	.01
	Preoutbreak (1959-1964 with postoutbreak (1969-1974)	
foliated host	5.210	.01
ndefoliated host	1.108	N.S.
inned, defoliated host	2.505	.05
nhost	4.856	.01
	Outbreak (1965-1968) with postoutbreak (1969-1974)	
foliated host	14.650	.01
ndefoliated host	.681	N.S.
inned, defoliated host	7.330	.01
nhost	.258	N.S.









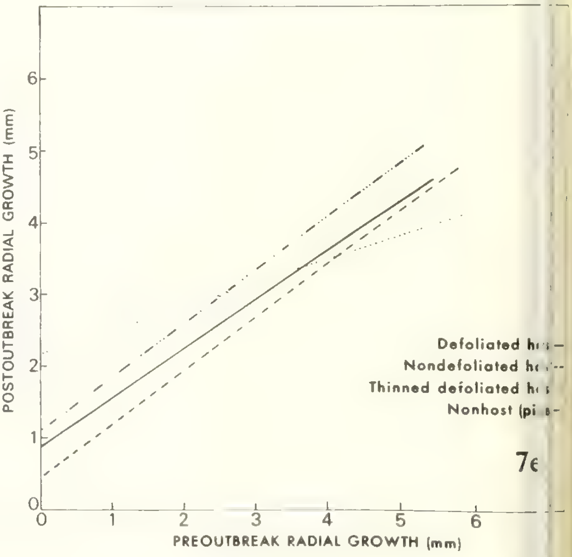


Figure 7.—a, Defoliated host radial gro h; b, nondefoliated host radial gro h; c, nonhost (pine) radial gro h; d, thinned defoliated host radial gro h; e, comparison of preoutbreak r al growth with postoutbreak growth.

sting for differences in intercept showed a
nificant difference (.05 level) in the post-
tbreak growth rate for nonhost (pine) over
foliated host and for both pine and de-
iated host over nondefoliated host. In
ier words, both classes of trees in the
ested area have responded with signifi-
ntly greater growth rates in the 6-year
stoutbreak period than nearby nonde-
iated white fir, which remained fairly
nstant. This implies that postoutbreak
wth increases in the outbreak area were
bably not unduly influenced by environ-
ntal factors.

PINE/WHITE FIR RELATIONS

Investigators have noted for many years
t tussock moth outbreaks, especially the
nters of highest populations and defolia-
n, have often been located on ridge tops or
th slopes (Wickman 1963, Wickman et al.
73). These locations are usually the most
ic sites in mountainous areas, and the tree
cies growing there often reflect this rela-
n. In California, most outbreaks have oc-
red in mixed conifer stands, and in Modoc
unty most outbreaks have been in mixed
e-fir stands. Sometimes the overstory is
e and the understory fir (Mason and
ompson 1971). Southwood (1966) suggests
eral methods for measurement of associa-
n between species, particularly compari-
s of two faunas. We applied one of the
gested tests, a 2 by 2 contingency tabula-
, to two species of plants, pine and fir.
first tabulation is drawn to obtain a
untitative measure of the association of
ir on plots containing white fir.

ine[3]	A. Number of plots with white fir		
	Present	Absent	Total
rent	a = 57	b = 3	60
bent	c = 178	d = 47	225
	235	50	285

(ad - bc) = 2145 or a positive association.

A chi-square test was made where $\chi^2 = 7.205$, indicating a positive association which was not the result of chance or an interaction between the two species.

Because pine and fir are broadly intermixed throughout much of the infestation, this statistic does not tell us much. We are particularly interested in those areas where defoliation was severe enough to cause tree mortality. So a second tabulation was drawn comparing plots with white fir mortality associated with pine.

B. Pine	A. Plots with white fir mortality		
	Present	Absent	Total
Present	a = 41	b = 19	60
Absent	c = 89	d = 136	225
	130	155	285

A similar test produces $\chi^2 = 14.67$ and a positive association that was not the result of chance.

This implied relation of pine with centers of severe defoliation and tree mortality was pursued further by comparing the percent white fir mortality on blocks of sample plots with percent pine. Figure 8 shows the arrangement of blocks of plots used for the analysis. Blocks were divided on the basis of topography (elevation) and equal numbers of plots as closely as possible. An average of 32 plots was in each block; block number 9 had only 16 plots because of its unusual configuration. A regression analysis (fig. 9) indicates a positive correlation of pine and white fir mortality ($R^2 = .895$ significant at the .01 level). The correlation shows an interesting trend and indicates that highest tree mortality occurred on the sites supporting the most ponderosa pine. These are probably the driest ones where fir grows in this area.

---

uch a tabulation should be drawn so that A is more
u ant than B.

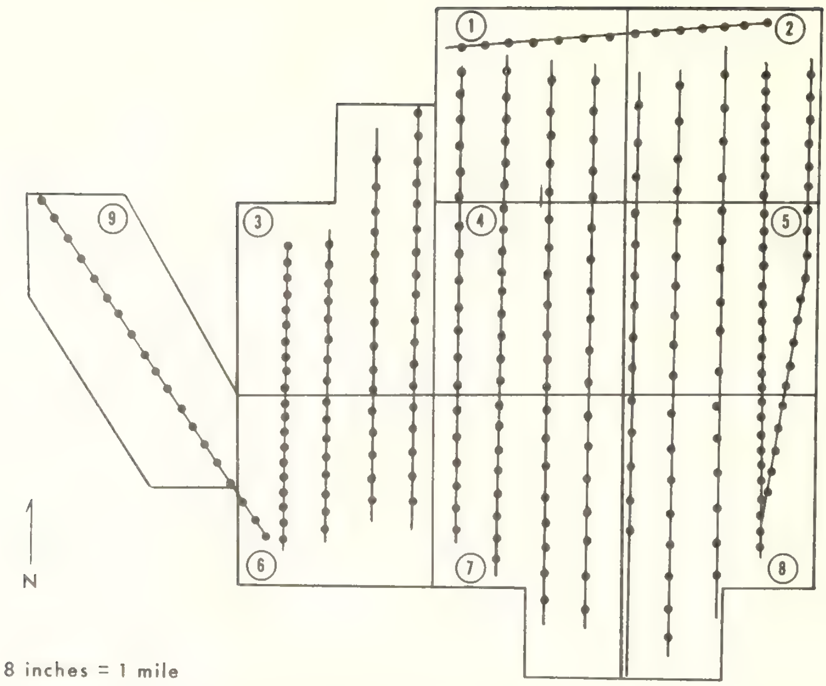


Figure 8.—Blocks of sample plots, arranged with nearly equal numbers of plots, used to compare white fir mortality with presence of pine.

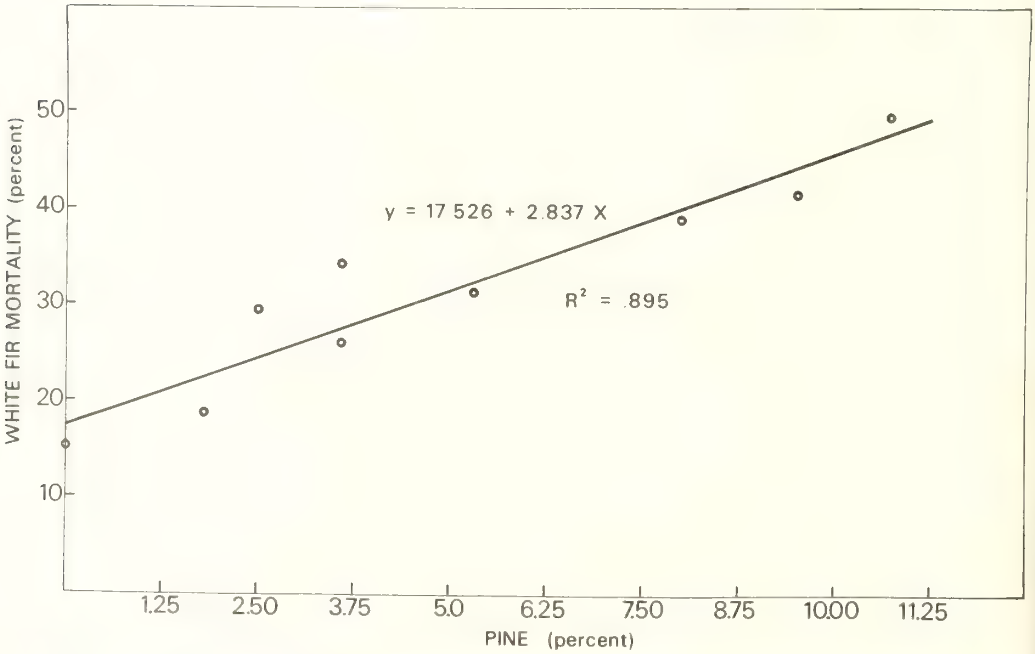


Figure 9.—Relation of white fir mortality to percentage of ponderosa pine in plots.

TREE SPECIES COMPOSITION

he outbreak area contains four conifer species: white fir, ponderosa pine, hoe pine (very similar to ponderosa pine), western juniper. An examination of pos- changes in overstory species composition he short-term (10-year) period was at- pted by comparing the standard plant ogy parameters of density, dominance, frequency. The following results and lusions are descriptive and are not based n statistical analysis. Relative values for were then obtained by the following ula:

$$\text{ative density} = \frac{\text{density for a species}}{\text{total density for all species}} \text{ X } 100$$

Table 11 presents these values for 1964 (preoutbreak), 1967 (immediate postoutbreak), and 1975 (10 years postoutbreak). Surprisingly, little change appears for white fir and pine in the "relative" values, especially as white fir suffered 32-percent stand mortality in 1964-1967. The largest change in the 10-year postoutbreak period is with western juniper, where relative values triple.

The relative values for density, dominance, and frequency are sometimes combined into an "importance" value, which reflects the importance of the species in the community (Lindsay 1956). The importance value is determined by the formula:

Importance value = relative density
+ relative dominance + relative frequency.

Table 11—Composition of white fir, pine, and western juniper for 1964, 1967, and 1975 based on living trees

or	Tree	1964	1967	1975
			Number	
ity	White fir	331.4	220.4	239.9
ber	Pine	18.8	18.1	16.6
acre)	Juniper	2.1	2.1	6.7
inance	White fir	193.2	142.0	132.4
l area	Pine	19.5	18.6	16.0
acre)	Juniper	1.0	1.0	2.1
uency	White fir	82.5	79.6	81.0
ber of plots	Pine	21.1	20.4	21.9
urrence/total plots)	Juniper	3.5	3.5	12.5
			Percent	
ive	White fir	94.1	91.6	91.1
ity	Pine	5.3	7.5	6.3
	Juniper	0.6	0.9	2.5
ive	White fir	90.4	87.9	88.0
inance	Pine	9.1	11.5	10.6
	Juniper	0.5	0.6	1.4
ve	White fir	77.0	76.9	70.2
uency	Pine	19.7	19.7	19.0
	Juniper	3.3	3.4	10.8

The importance values for the three species are calculated below to show the relations quantitatively.

Importance Values

	1964	1967	1975
White fir	261.5	256.4	249.3
Pine	34.1	38.7	35.9
Juniper	4.4	4.9	14.7

The importance-value decline for white fir was caused by tree mortality in 1964-67. The decline for the pine from 1967 to 1975 is suspected to be from a sampling error. The reason for the increased value for juniper in 1975 is unknown; it too may be an artifact of the sampling technique, or it could represent a delayed response to the outbreak. It was not caused by ingrowth, however, because most of the juniper were 6-in or larger d.b.h.

Discussion

Obviously severe defoliation by the Douglas-fir tussock moth can cause heavy tree mortality. All of the outbreaks that have been studied to date, however, have exhibited a common pattern. Namely, mortality tends to be concentrated in patches that range in size from several to several hundred acres, depending on the size of the outbreak. The mortality occurring in these patches is severe, averaging about 84 percent of the trees; and the end result, even if the trees are salvaged to negate the economic loss, is a scattering of understocked chunks of land with loss of potential future growth. This also results in the added costs of adjusted timber management plans. The total area of these scattered patches is relatively small, however, usually 10 to 14 percent of the outbreak area. Perhaps half of the additional tree mortality occurs as scattered single trees and small groups in the area surrounding the patches. This scattered mortality may be viewed as a short-term loss if salvage is not possible; however, ov rotation period, a reduction in stand den probably has positive values by lessening competition and enhancing growth of su vors. For instance, 10 years after the break, our measurements of advance re duction showed only a 9-percent reduc from the immediate postoutbreak per And regeneration counts (seedlings less t 10 years old) were back to the preoutbr level 10 years later. Fye and Thomas (19 found that 15 years after a spruce budw outbreak, balsam fir and spruce seedl released by the outbreak were growing rapidly that they were retarding the he growth of some reproduction. And Ghen al. (1957) showed that balsam fir seedl responded to killing of the overstory wi fivefold increase of height growth. Growth released reproduction, however, was twice as great as under suppressed conditi before the outbreak. He concluded that spruce budworm is itself a mechanism release of established seedlings and affects next forest no differently than other dis bances like cutting and fire.

Top-kill is usually negative in small tr because it prevents their growing into w formed crop trees. Surprisingly, on this trees top-killed by tussock moth gradu disappeared, probably from mortality by b beetles. If the disappearance of top-ki trees is part of the normal attrition withi stand, it may be improper to categorize this loss as damage done by defoliation.

The economic effects of short-term gro loss are extremely difficult to quantify cause of the many extrinsic factors affect growth, particularly precipitation and t competition.

Apparently the effect of defoliation growth of white fir was of short duration. T effects of tree mortality reducing competit and possibly the nutrient cycling of ins frass and damaged needles during the o break has resulted in significantly grea

vth of both host and nonhost trees
ecially the slower growing trees) during
postoutbreak period. Surprisingly, a posi-
growth trajectory has developed within a
ar period. An important aspect is, of
se, how long this relation will continue.
average age of defoliated white fir was 79
s and of nondefoliated pine, 92 years. If a
ervative rotation period of 120 years is
med, will accelerated growth of host and
nost for another 30 to 40 years plus
owth of smaller trees then compensate for
vth loss of the host alone during the
reak? The answer to this question obvi-
y needs continued study, but the implica-
of beneficial thinning effects of out-
ks in stand dynamics is intriguing and
rves further consideration.

his mixed bag of losses and gains from
liation leads one to ask, "What is the role
ne Douglas-fir tussock moth in western fir
sts?" Here is a native insect, which has
ted to survival in a forest type that is
lly undergoing changes caused mostly by
If recent large outbreaks in British
mbia and the Pacific Northwest are in-
ive of a trend, then these man-caused
ges may be creating conditions more
ptible to large outbreaks. Because we
ot look at the insect system separately
the forest system, I propose that there
everal processes going on in the forest
e, during, and after an outbreak that
ate the tussock moth is either a precursor
astic successional changes or at least an
ator of unstable forest systems.

st, if one agrees with the hypothesis of
on and Addy (1975) and others that
phagous insects are regulators of forest
ry production, then the Douglas-fir
ck moth is a classic example of such a
netic regulator. The characteristics of
s acting as such a regulator as defined in
Emden (1973) are as follows: They
a plant's primary site of energy and
emical synthesis by consuming foliage;
l species of phytophagous insects are
usually coextensive with a plant species so the plant almost always has an ubiquitous consumer (e.g., the Douglas-fir tussock moth, the Modoc budworm, and various loopers on white fir); and a long history of association and coevolution between insect and host has occurred.

As Mattson and Addy point out, this implies that insects, as regulators, can and do respond to changes in condition of the host, and the host-plant systems react and change both as individual trees and in stands to changes in their insect consumers. For instance, Kimmins (1972) has suggested that defoliations contribute additional nutrients to the soil. And Assmann (1970) claims that the weakened, old, and suppressed plants that usually die after defoliation result in more available nutrients, light, heat, and moisture for the survivors. Loucks (1970) goes a step further and says that drastic, natural, periodic disturbances are necessary every 50 to 100 years to return plant communities to an earlier successional stage, which affects species diversity and primary production. Taken together and given the lately increased understanding of plant ecosystems, lends credance to the concept that the tussock moth is playing a natural and, in the long term, beneficial role as a system regulator. This brings me to my second point: the effect of the host-plant system on the insect.

Over my 22 years of association with tussock moth outbreaks, I have observed an increasing tendency of outbreaks to occur in second-growth fir stands, often in association with pine. Sometimes the pine occurs as a definite overstory as in the Corral Creek, California, outbreak (Mason and Thompson 1971). The results of the study reported here are also intriguing in the association with pine. My hypothesis is that because of man's management practices over the past 75 years or so of harvesting overstory pine and excluding fire, we have favored an increase in the proportion of white fir on pine sites, thus creating vast acreages of susceptible host stands throughout the West. Many of these stands are on xeric sites which are also apparently most suitable for the development and outbreak of tussock moth populations.[4] These successional patterns have been recorded by many foresters, and Franklin and Dyrness (1973) neatly summarized the condition for pine/fir sites in eastern Oregon similar to those in northeastern California. In short, periodic fires in the past helped maintain ponderosa pine stands. Fire control over the last 75 years has, in more moist sites, resulted in the replacement of ponderosa pine with white fir. This process has probably been speeded up wherever man logged pine from the stand.

Enter the tussock moth: the severe, though localized, outbreaks in California in 1936-37 and 1955-56 caused heaviest damage in old-growth, mixed-conifer stands. Since that time, outbreaks in California have occurred mostly in second-growth or undergrowth stands of white fir, usually in association with ponderosa pine. This relation has also been observed in the Blue Mountains of Oregon and Washington (Wickman 1978), although serious damage centers also occurred in old-growth stands of pure grand fir. And Stoszek (1977) notes that in recent Idaho outbreaks grand fir in stands with high-graded pine overstory suffered the greatest defoliation.

There are more influences on the development of outbreaks than exclusion of fire, high-grading pine, or increased host acreage on xeric sites. The responses of the tussock moth to foliage quality are probably very important (Beckwith 1976). Southwood (1973) contends that plant foliage is only marginally adequate nutritionally for insect consumers, and these consumers will react to small biochemical changes in plants caused by aging, fluctuations in soil moisture, pollution, or other stresses. The effects of weather on populations should also be considered. Morris (1963) has indicated that several summers of dry, warm weather appear to facilitate
breaks of spruce budworm. Subnormal pr
itation was noted for several years before
tussock moth outbreaks in Califc
(Wickman 1963).

Also to be considered are the influenc
a large array of natural enemies of the tus
moth. We know very little about their ro
"releasing" outbreaks or possibly in prev
ing them in certain stands exhibiting favor
environmental conditions for the nat
enemies. Research of this type under
may provide valuable leads for understan
these relations.[5]

Possibly recent changes in host stands
causing changes in host-plant quality
quantity that could also be influencing
habitats of natural enemies including
tussock moth and thus their responses to t
hosts. These changes combined with
influences of weather on insect, nat
enemies, and host could, in turn, resul
large and damaging tussock moth outbre

If we can accept the natural role of
tussock moth in, or as a result of, our
and changing forests, then perhaps we sh
look at the insect in a new light. Maybe
tussock moth is doing us a favor, by poin
out the fallacy of some of our forest man
ment practices and acting as a regulator i
unstable system that we have created
vast acreages.

I don't mean to imply that whole
conversion of fir/pine forests to pine
solve the problem. The bark beetle probl
associated with unmanaged, second-gro
stands of pine in the west are commonp
and of much greater magnitude than lo
caused by Douglas-fir tussock moths.
principle of pest control by host managem
has been suggested by many as a solutio
problems with defoliating insects; howeve
pointed out by Baskerville (1975) for

---

[4] R. R. Mason, USDA For. Serv., For. Sci. Lab., Corvallis, Oreg., personal communication.

[5] T. R. Torgersen and R. R. Mason, USDA For. Serv.
Sci. Lab., Corvallis, Oreg., personal communications.

uce budworm, some serious problems limit plementation. I do suggest that the risk of ure Douglas-fir tussock moth outbreaks, least in white fir forests, could probably lessened by changes in our silvicultural ctices.

One thing is heartening—the Douglas-fir sock moth does not destroy entire white forests in California and rarely decimates uglas-fir forests elsewhere. Patches of trees y be severely defoliated and die on some of outbreak areas; additional scattered tree rtality occurs and this is probably bene- al in terms of thinning the stand. For eral years after an outbreak growth may line, but recovery is usually dramatic. ests are remarkably resilient, and even n has to work hard at devastating one. we Reservoir is a case in point. Man-caused urbances have included: logging twice, lusion of fire, heavy sheep grazing before 0, continued cattle grazing, building of ds and recreation facilities, and spraying h malathion in 1964 and DDT in 1965. In trast, the one major natural disturbance record is the 1964-1965 tussock moth break. Did it hurt the forest? Did it help forest? I wish I could be around in 2065 ruise the Stowe Reservoir outbreak area find out.

Acknowledgments

want to thank the contributions of my eagues at the Forestry Sciences Labora-, Drs. R. R. Mason and R. W. Campbell as as Dr. K. W. Seidel of the Forest Service cultural Laboratory in Bend, Oregon, and Donald Zobel, Oregon State University, helpful reviews and comments. I am icularly indebted to D. L. Henshaw, hematical Technician, for programming and analysis. The study would not have possible without the continued interest protection of the study area by the doc National Forest. Research leading to this publication was funded in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

References Cited

Assmann, E. 1970. The principles of forest yield study. Pergamon Press, New York. 506 p.

Baskerville, G. L. 1975. Spruce budworm: The answer is forest management: or is it? For. Chron. 51(4): 23-26.

Beckwith, R. C. 1976. Influence of host foliage on the Douglas-fir tussock moth. Environ. Entomol. 5(3): 73-7.

Franklin, J. F., and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p.

Fye, R. E., and J. B. Thomas. 1963. Regeneration of balsam fir and spruce about 15 years after release by spruce budworm attack. For. Chron. 39: 385-396.

Ghent, A. W., D. A. Fraser, and J. B. Thomas. 1957. Studies of regeneration in forest stands devastated by the spruce budworm. I. Evidence of trends in forest succession during the first decade following budworm devastation. For. Sci. 3: 184-208.

Kimmins, J. P. 1972. Relative contributions of leaching, litter-fall and defoliation by *Neodiprion sertifer* (Hymenoptera) to the removal of cesium-134 from red pine. Oikos 23: 226-234.

Lindsay, A. A. 1956. Sampling methods and community attributes in forest ecology. For. Sci. 2: 287-296.

Loucks, O. L. 1970. Evaluation of diversity, efficiency, and community stability. Amer. Zool. 10: 17-25.

Luck, R. F., and D. L. Dahlsten. 1967. Douglas-fir tussock moth (*Hemerocampa pseudotsugata*) egg-mass distribution on white fir in northeastern California. Can. Entomol. 99(11): 1193-1203.

Mason, R. R., and C. G. Thompson. 1971. Collapse of an outbreak population of the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). USDA For. Serv. Res. Note PNW-139. 10 p.

Mattson, W. J., and N. D. Addy. 1975. Phytophagous insects as regulators of forest primary production. Science 190: 515-522.

Morris, R. F. 1963. Budworm dynamics. Mem. Entomol. Soc. Can. 31. 332 p.

Seidel, K. W. 1977. Suppressed grand fir and shasta red fir respond well to release. USDA For. Serv. Res. Note PNW-288. 7 p.

Snedecor, G. W., and Cochran, W. G. 1967. Statistical methods. Sixth edition. Iowa State Univ. Press, Ames. 593 p.

Southwood, T. R. E. 1966. Ecological methods. Methuen and Co. Ltd., London. 391 p.

Southwood, T. R. E. 1973. Introduction–The insect/plant relationship-An evolutionary perspective. *In* Insect-plant relationships. H. F. Van Emden (Ed.) Blackwell, Oxford. p 3-30.

Stoszek, K. J. 1977. Factors influencing tree and stand susceptibility to Douglas-fir tussock moth attack. Entomol. Soc. Amer. Bull. 23: 171-2.

Van Emden, H. F. (Ed.). 1973. Insect-pla relationships. Blackwell, Oxford. 213

Wert, S. L., and B. E. Wickman. 1968. Whi fir stands killed by tussock moth .. 70-mm color photography aids dete tion. USDA For. Serv. Res. No PSW-168. 5 p.

Wert, S. L., and B. E. Wickman. 1970. Impa of Douglas-fir tussock moth . . . col aerial photography evaluates mortalit USDA For. Serv. Res. Pap. PSW-60. 6

Wickman, B. E. 1963. Mortality and growt reduction of white fir following defoli tion by the Douglas-fir tussock mot USDA For. Serv. Res. Pap. PSW-7. 15

Wickman, B. E. 1978. Tree mortality an top-kill related to defoliation by th Douglas-fir tussock moth in the Blu Mountains outbreak. USDA For. Ser Res. Pap. PNW-233. 47 p., illus.

Wickman, B. E., R. R. Mason, and C. Thompson. 1973. Major outbreaks the Douglas-fir tussock moth in Orego and California. USDA For. Serv. Ge Tech. Rep. PNW-5. 18 p.

Wickman, B. E., and Donald A. Renton. 197 Evaluating damage caused to a cam ground by Douglas-fir tussock mot USDA For. Serv. Res. Note PNW-25 5 p.

stand conditions 10 years later. USDA For. Serv. Res. Pap. PNW-244, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Tree damage occurring immediately after an outbreak of Douglas-fir tussock moth, *Orgyia Pseudotsugata* McD., and stand conditions 10 years later are described. Because of increased radial growth and ingrowth in the 10-year postoutbreak period, good evidence indicates that tree damage caused by the tussock moth may not be as severe in the overall stand dynamics as previously pictured. The insect probably plays a key role as a phytophagous regulator of primary production in some second-growth white fir stands in California and elsewhere.

KEYWORDS: Insect damage (-forest, Douglas-fir tussock moth, *Orgyia Pseudotsugata*

Wickman, Boyd E.
1978. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. USDA For. Serv. Res. Pap. PNW-244, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Tree damage occurring immediately after an outbreak of Douglas-fir tussock moth, *Orgyia Pseudotsugata* McD., and stand conditions 10 years later are described. Because of increased radial growth and ingrowth in the 10-year postoutbreak period, good evidence indicates that tree damage caused by the tussock moth may not be as severe in the overall stand dynamics as previously pictured. The insect probably plays a key role as a phytophagous regulator of primary production in some second-growth white fir stands in California and elsewhere.

KEYWORDS: Insect damage (-forest, Douglas-fir tussock moth, *Orgyia Pseudotsugata*

stand conditions 10 years later. USDA For. Serv. Res. Pap. PNW-244, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Tree damage occurring immediately after an outbreak of Douglas-fir tussock moth, *Orgyia Pseudotsugata* McD., and stand conditions 10 years later are described. Because of increased radial growth and ingrowth in the 10-year postoutbreak period, good evidence indicates that tree damage caused by the tussock moth may not be as severe in the overall stand dynamics as previously pictured. The insect probably plays a key role as a phytophagous regulator of primary production in some second-growth white fir stands in California and elsewhere.

KEYWORDS: Insect damage (-forest, Douglas-fir tussock moth, *Orgyia Pseudotsugata*

Wickman, Boyd E.
1978. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. USDA For. Serv. Res. Pap. PNW-244, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Tree damage occurring immediately after an outbreak of Douglas-fir tussock moth, *Orgyia Pseudotsugata* McD., and stand conditions 10 years later are described. Because of increased radial growth and ingrowth in the 10-year postoutbreak period, good evidence indicates that tree damage caused by the tussock moth may not be as severe in the overall stand dynamics as previously pictured. The insect probably plays a key role as a phytophagous regulator of primary production in some second-growth white fir stands in California and elsewhere.

KEYWORDS: Insect damage (-forest, Douglas-fir tussock moth, *Orgyia Pseudotsugata*

Mason, R.
Collap
the D
campo
Lyma
Note
Mattson,
Phyto
forest
515-5
Morris, R.
Mem.
Seidel, K.
shasta
USDA
7 p.
Snedecor,
Statis
State
Southwooc
ods.
391 p
Southwooc
insect,
perspe
H. F
Oxfor
Stoszek, K
and s
tussoc
Amer.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

1978
Research Paper PNW-245

REGENERATION OF TREE SEEDLINGS AFTER CLEARCUTTING ON SOME UPPER-SLOPE HABITAT TYPES IN THE OREGON CASCADE RANGE

MICHAEL J. SULLIVAN

OREGON UNIVERSITY LIBRARY
JAN 12 1979
SCI. TECH. & AGR. DIV.

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Contents

Page

INTRODUCTION 1

DESCRIPTION OF STUDY AREA 1
- Location and General Characteristics. 1
- Topography and Geology. 1
- Soils 1
- Climate 2
- Vegetation. 2

METHODS. 4
- Reconnaissance and Choice of Study Units. . . 4
- Collection of Data. 4
- Analysis of Data. 5

RESULTS AND DISCUSSION 5
- Stocking in Relation to Habitat Type. 5
- Seedling Growth in Relation to Habitat Type . 11
- Plant Community Development on Upper-Slope Clearcuts 12

SILVICULTURAL IMPLICATIONS 14

CONCLUSIONS. 16

LITERATURE CITED 16

Acknowledgment

This paper was developed from a thesis, "Stocking levels and seedling heights on clearcuts in relation to habitat type in the western Cascades of Oregon" (1976), written in partial fulfillment of the requirements for the degree of Master of Science, Oregon State University. The work was supported in part by a Mary McDonald Fellowship provided the author during his residence. Dr. William K. Ferrell, Professor of Forestry at Oregon State University, served as the major advisor and his assistance and advice are gratefully acknowledged. The Pacific Northwest Forest and Range Experiment Station provided technical advice during the conduct of the study and partial financial support for preparation of this report.

Michael J. Sullivan is now a hydrologist with the National Weather Service River Forecast Center, Cincinnati, Ohio.

REGENERATION OF TREE SEEDLINGS AFTER CLEARCUTTING ON SOME UPPER-SLOPE HABITAT TYPES IN THE OREGON CASCADE RANGE

Reference Abstract

Sullivan, Michael J.
1978. Regeneration of tree seedlings after clearcutting on some upper-slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Describes survival and growth of tree seedling regeneration on five upper-slope habitats in the Oregon Cascade Range. Distinct differences exist between habitat types in both stocking potential and growth.

KEYWORDS: Regeneration (artificial), forest types, vegetation types, seedling growth, logging (-regeneration, Oregon (Cascade Range), *Abies amabilis*.

RESEARCH SUMMARY
Research Paper PNW-245
1978

Stocking characteristics and tree seedling growth to ages 5 and 7 were measured on 45 study units, representing five habitat types, established on clearcuts in the *Abies amabilis* Zone of the Western Cascades of Oregon. Units ranged from 6 to 30 acres (2.4 to 12 hectares) in size and from 7 to 15 years in age (time elapsed since harvest); they occupied a variety of slope aspects, inclinations, and topographic positions. Distinct differences exist between the habitat types in stocking potential after they are clearcut. The importance of individual tree species, the average height of tree seedlings at a given age, and some aspects of structure and composition of successional plant communities also vary substantially with habitat type. Results were used to formulate preliminary regeneration guidelines for the habitat types studied. Habitat type appears to be a potentially productive tool for foresters involved with regeneration management in the *Abies amabilis* Zone of the Western Cascades of Oregon.

Introduction

In the Western Cascades of Oregon, preliminary forest habitat types have only recently been identified (Dyrness et al. 1974); management guidelines based on them have yet to be developed.

In northern and portions of the central Rocky Mountains basic habitat type classifications have been largely completed and actual mapping of habitat types has been undertaken. Many silvicultural properties of forest land, including regeneration characteristics, have been shown to be well correlated with habitat type in the northern Rocky Mountains (Layser 1974). In the Pacific Northwest, however, the implementation of forest habitat type classification has not reached a comparable level of development. These forests fall within two major vegetation zones, the *Tsuga heterophylla* and the *Abies amabilis*,[1] each defined by its dominant climax tree species. Greater obstacles to successful regeneration after timber harvest are generally encountered within the subalpine *Abies amabilis* Zone. Seedling environments are often harsh, and regeneration failures are not unusual after clearcut operations.

The purpose of this research was to relate regeneration success, as measured by stocking percentage and tree seedling growth, to habitat type on clearcuts in the *Abies amabilis* Zone of the Western Cascades of Oregon. For the *Abies amabilis* Zone, the results provide a first evaluation of the utility of habitat type classification in regeneration management and insight into regeneration problems associated with clearcuts. Information on early stages of plant succession on clearcuts is a byproduct.

Description of Study Area

LOCATION AND GENERAL CHARACTERISTICS

The study area encompasses 375 km^2 (150 mi^2) and is located within the Willamette National Forest approximately 72 km (45 mi) northeast of Eugene, Oregon (fig. 1). The area falls within the administrative jurisdiction of three Ranger Districts: Sweet Home, Blue River, and McKenzie Bridge. The H. J. Andrews Experimental Forest and the Wildcat Mountain Research Natural Area are also located within the study area.

TOPOGRAPHY AND GEOLOGY

The area is a region of mature landforms, possessing strongly dissected ridge and valley topography. Slopes are generally steep, but some areas at higher elevations are characterized by immature, rolling topography. Elevations range from 460 to 1 750 m (1,510 to 5,741 ft).

The study area lies within the major geologic province known as the Western Cascades and is characterized by massive accumulations of volcanic material of Eocene through Pliocene age (Peck et al. 1964, Swanson and James 1975). Exposed rock of the *Abies amabilis* Zone of the study area is typically composed of andesitic and basaltic flows, breccias, and lapillus tuffs. Surface deposits of volcanic tephras are not uncommon.

SOILS

Dyrness et al. (1974) reported that the soils at the higher elevations of the H. J. Andrews Forest (generally representative of the study area) could be grouped into three associations: andesitic soils which are weakly developed and have textures from loams to sandy loams; Ando-like soils derived from andesite and basalt and with loam to silt loam textures; and Brown Podzolic soils derived from andesite and basalt, and loamy in texture. Characteristically, these soils are well drained, moderately stony, and relatively shallow--1 to 3 m (3 to 9 ft).

---

[1] Scientific names are from Hitchcock and Cronquist (1973).

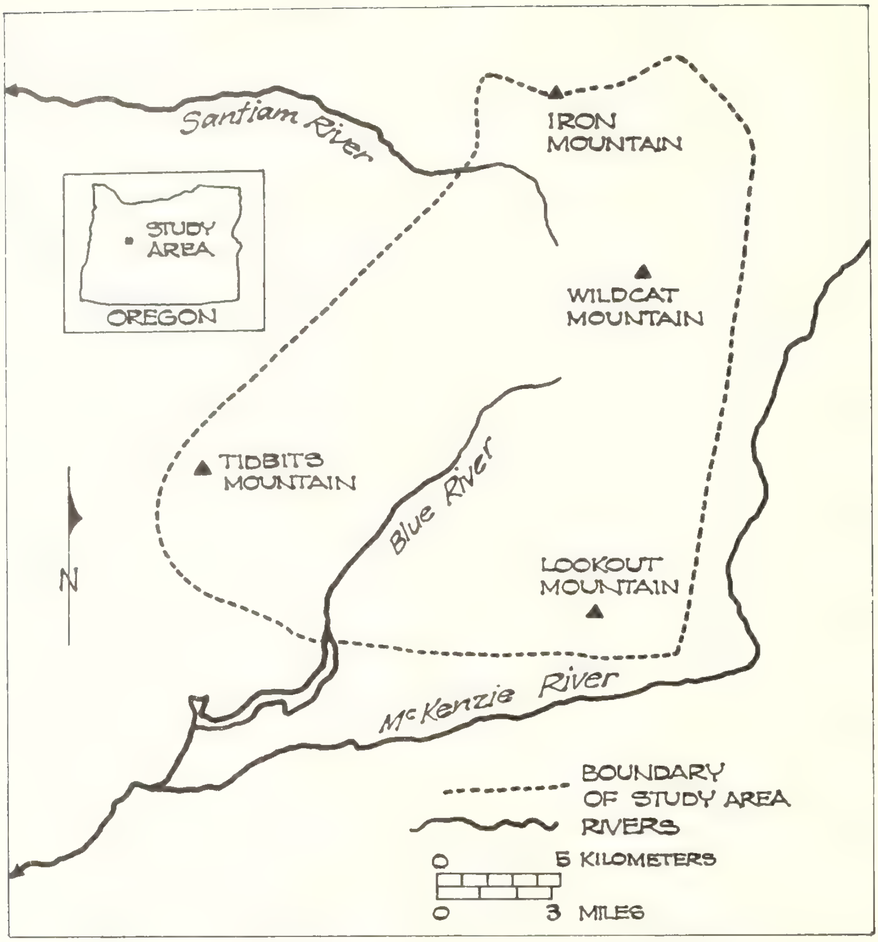


Figure 1.--Location of study area.

CLIMATE

The climate of the study area is characterized by relatively mild, wet winters and warm, dry summers. The climate at higher elevations (within the *Abies amabilis* Zone) is considerably more severe than that at lower elevations where most climatic data have been gathered. Within the *Abies amabilis* Zone the winter snowpack commonly ranges from 1 to 3 m in depth. Recently gathered data indicate that mean January air temperatures (under forest canopies 1 m above the forest floor) range from about -0.7° to -2.4°C (28° to 31°F), and mean July air temperatures range from about 14° to 15.5°C (57° to 60°F).[2] Annual precipitation is estimated to range from 2 470 to 3 460 mm (98 to 136 in) at the higher elevations (Legard and Meyer 1973). Clear atmospheric conditions and low precipitation usually prevail during the summer.

VEGETATION

The study area lies within the Willamette ecologic province defined for the true fir-hemlock forests (Franklin 1965). *Abies amabilis* habitat types occur at the higher elevations of the study area and are generally found on the upper slopes of ridge systems and summits. Wildfires have been sufficiently frequent in the study area to prevent extensive development of forest stands to the full climax state. As a result,

---

[2] Unpublished data for 1973 and 1974, on file at the Forest Research Laboratory, Oregon State University, Corvallis.

Pseudotsuga menziesii and *Abies procera*, distinctly seral species, are often the overstory dominants of forest stands within the *Abies amabilis* Zone. Tree species common to the *Abies amabilis* Zone of the study area are listed in table 1.

Table 1--*Tree species of the* Abies amabilis *Zone of the study area*

Tree species	Importance[1]
Abies amabilis (Pacific silver fir)	M
Abies procera (noble fir)	M
Pseudotsuga menziesii (Douglas-fir)	M
Tsuga heterophylla (western hemlock)	M
Tsuga mertensiana (mountain hemlock)	m
Pinus monticola (western white pine)	m
Chamaecyparis nootkatensis (Alaska-cedar)	m
Thuja plicata (western redcedar)	m
Abies grandis (grand fir)	m
Libocedrus decurrens (incense-cedar)	m
Picea engelmannii (Engelmann spruce)	i
Pinus contorta (lodgepole pine) var. *latifolia*	i
Pinus ponderosa (ponderosa pine)	i
Abies lasiocarpa (subalpine fir)	i

[1] M = major importance, m = minor importance, i = insignificant.

Dyrness et al. (1974) identified and described seven *Abies amabilis* Zone climax communities (habitat types) occurring within the study area:

> The *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax* association (Abam-Tsme/Xete).
>
> The *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax* association (Abam/Vame/Xete).
>
> The *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis* association (Abam/Rhma-Vaal/Coca).
>
> The *Abies amabilis/Vaccinium alaskaense/Cornus canadensis* association (Abam/Vaal/Coca).
>
> The *Abies amabilis/Achlys triphylla* association (Abam/Actr).
>
> The *Abies amabilis/Tiarella unifoliata* association (Abam/Tiun).
>
> The *Chamaecyparis nootkatensis/Oplopanax horridum* association (Chno/Opho).

An eighth, previously undocumented, habitat type was recognized within the study area. *Abies amabilis* is the dominant climax tree species, and *Rhododendron macrophyllum* dominates the shrub layer. *Vaccinium alaskaense*, however, is either absent or insignificant, whereas *Vaccinium membranaceum* is typically present. For purposes of this analysis, this habitat type is designated the Abam/Rhma-Vame.

Cumulatively, these habitat types occupy a great deal of acreage in the northern Oregon and southern Washington Cascade Range. Several types, most notably the Abam/Vame/Xete, Abam/Vaal/Coca, and Abam/Actr are particularly widespread, both geographically and in total acreage (see, for example, Franklin 1966).

Methods

RECONNAISSANCE AND CHOICE OF STUDY UNITS

Before the study units were established, a detailed examination was made of Forest Service regeneration records to determine the general nature of clearcuts within the study area. Age, elevation, slope characteristics, site preparation, and regeneration histories were recorded for each clearcut thought likely to be located on *Abies amabilis* Zone habitat types. A field reconnaissance of these clearcuts, limited to those aged 7 to 15 years (harvested from 1960 to 1968) was subsequently undertaken. The limitation insured that each clearcut examined had ample time to regenerate; it also resulted in a satisfactory number of clearcuts for reconnaissance purposes.

A total of 121 clearcuts were examined in the field. A key developed by Dyrness et al. (1974) was used to classify habitat types. The habitat type of each clearcut was identified after examination of the vegetation of both the clearcut and surrounding, undisturbed stands thought to possess environments similar to that of the clearcut. Comparisons were based on factors such as similarity in slope, aspect, and landform.

Of the 121 clearcuts examined in the field, 52 were discarded from further consideration as unsuitable for study. Criteria for dismissal included: clearcut not on *Abies amabilis* habitat type; clearcut lacking uniformity on 5 or more acres because of broken topography, with major shifts in slope and/or aspect; clearcut heavily disturbed by roads or earth movements.

From the remaining clearcuts, 45 units, encompassing five habitat types, were chosen for detailed study. The habitat types and the number of units established in each type are:

Habitat type	Study units
Abam/Rhma-Vaal/Coca	11
Abam/Rhma-Vame	4
Abam/Actr	15
Abam/Vame/Xete	8
Abam-Tsme/Xete	7

In almost all cases the study units were not entire clearcut units but were portions thereof (from one-quarte to three-quarters of an entire clearcu and from 6 to 30 acres (2.4 to 12 ha) in size), on which habitat type and slope aspect and inclination as determined by compass and abney level were relatively uniform. Of the 45 study units, 42 were slash burned (93 percen 36 were planted (to Douglas-fir, noble fir, or western white pine) at least once (80 percent), 10 were seeded (to Douglas-fir, noble fir, or western white pine) at least once (22 percent) and 41 of the units were planted and/o seeded at least once (91 percent). None of the units had been treated with herbicides or fertilizer. Enviro mental and treatment data for the individual areas are tabulated in appendix I of Sullivan.[3]

COLLECTION OF DATA

A systematic sampling technique with a random element to determine specific locations for circular, 1-milacre (4.05-m^2) plots, was used. It entailed the use of parallel transects with fixed plot intervals (40 to 100 ft (12 to 30 m), depending on the study unit sampled) oriented perpendicularly to the slope. A random number table was used to position each plot a random number of paces perpendicular right or left from the fixed plot interval along the transect line. This procedure established the center of each plot. The sampling intensity on individual study units ranged from 0.5 to 1.5 percent of the unit area.

The following data were collected on each milacre plot: (1) stocking condition (stocked or not stocked);

---

[3] Sullivan, Michael James. 1976. Stocking levels and seedling heights on clearcuts in relation to habitat type in the western Cascades of Oregon. M.S. thesis, 81 p. (On file at Oreg. State Univ., Corvallis, Oreg.)

(2) number and species of trees present; (3) time of origin of each tree present, i.e., postharvest regeneration (originating after cutting) or advance regeneration (present before cutting); (4) height of each tree seedling at ages 5 and 7; (5) estimated percent canopy cover of shrub species and the herbs *Xerophyllum tenax* and *Pteridium aquilinum* (Daubenmire 1959).

Stocking determination was weighted by seedling age; a plot was stocked if it contained one of the following:

at least five 1-year-old trees,
at least three 2-year-old trees,
at least two 3-year-old trees, or
at least one 4-year-old tree.

Time of origin of trees present on sample plots was determined from the number of branch whorls and bud scale scars. Any tree older than the clearcut itself was classified as advance regeneration.

Tree seedling heights were determined as follows: the age of the seedling was estimated from a careful count of the number of branch whorls and bud scale scars; height was then measured at points corresponding to ages 5 and 7.

Cover percentage was estimated for all shrub species except trailing species, which typically contributed little to the total shrub cover of the units sampled. Because of time limitations, cover was estimated for only the two most important herbaceous species, *Xerophyllum tenax* and *Pteridium aquilinum.*

ANALYSIS OF DATA

Based on data collected in the field, several variables were derived s follows: (1) the stocking per-entage of each study unit was the atio of number of plots stocked to umber of plots established multi-lied by 100; (2) the number of rees per acre of each study unit as the total number of trees counted n all plots divided by the total umber of plots established and multiplied by 1,000 to convert from a milacre to an acre basis; (3) the adiation index of each study unit was derived from measurements of slope aspect and inclination and tables prepared by Frank and Lee (1966); (4) the percent shrub cover of each study unit was the total cover percentages of each plot summed for all plots and divided by the total number of plots established.

Results and Discussion

STOCKING IN RELATION TO HABITAT TYPE

Differences in Stocking Among Habitat Types

Distinct differences exist among the stocking levels of the habitat types (table 2); an analysis-of-variance shows statistical significance at the 0.01-probability level. The Abam/Rhma-Vaal/Coca and Abam/Rhma-Vame habitat types show substantially higher mean stocking percentages than the other three types. For postharvest regeneration, this is supported by results of a multiple range test (table 3); differences between the Abam/Rhma-Vaal/Coca and Abam/Rhma-Vame habitat types are not significant but both differ significantly from the other three. Highly variable levels of advance stocking, possibly caused by variations in logging disturbance, slash treatment, and other site preparation activities, reduce the statistically significant differences (table 4).

Factors Affecting Differences in Stocking

Mean values for radiation index, elevation, and percent of shrub cover for each habitat type were compared with mean postharvest stocking percentage to see if differences in stocking were related to environment (table 5). Coefficient of determination (R^2) between mean stocking and several variables is:

Radiation index	0.825
Elevation	.604
Shrub cover	.047
Radiation index *X* elevation	.916

Radiation index and elevation are inversely related to stocking; a

Table 2--*Mean and median stocking percentages (all species combined) of clearcut study areas stratified by habitat type*

Habitat type[1]	Postharvest stocking percentage		Advance stocking percentage	
	Mean	Median	Mean	Median
Abam/Rhma-Vaal/Coca	48.3	48.9	16.5	8.9
Abam/Rhma-Vame	44.1	41.6	14.0	5.4
Abam/Vame/Xete	20.1	19.1	2.0	1.3
Abam/Actr	18.7	17.1	2.7	2.3
Abam-Tsme/Xete	[2]14.4	8.5	3.1	1.4

---

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

[2] Mean strongly influenced by one study unit with 50-percent stocking; the other sampling units of this habitat type had less than 16-percent stocking.

Table 3--*Significance of differences in postharvest mean stocking percentages between habitat types*[1] [2]

Habitat type	Abam/Rhma-Vaal/Coca	Abam/Rhma-Vame	Abam/Vame/Xete	Abam/Actr	Abam-Tsme/Xete
Abam/Rhma-Vaal/Coca	--	NS	**	**	**
Abam/Rhma-Vame		--	*	**	**
Abam/Vame/Xete			--	NS	NS
Abam/Actr				--	NS
Abam-Tsme/Xete					--

---

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

[2] * = significance at the 0.05-probability level; ** = significance at the 0.01-probability level; NS = nonsignificance.

Table 4--*Significance of differences in advance mean stocking percentages between habitat types*[1] [2]

Habitat type	Abam/Rhma-Vaal/Coca	Abam/Rhma-Vame	Abam/Vame/Xete	Abam/Actr	Abam-Tsme/Xete
Abam/Rhma-Vaal/Coca	--	NS	*	**	**
Abam/Rhma-Vame		--	NS	NS	NS
Abam/Vame/Xete			--	NS	NS
Abam/Actr				--	NS
Abam-Tsme/Xete					--

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

[2] * = significance at the 0.05-probability level; ** = significance at the 0.01-probability level; NS = nonsignificance.

Table 5--*Mean values of selected environmental parameters of clearcut study areas stratified by habitat type*

Habitat type[1]	Postharvest stocking	Radiation index	Shrub cover	Elevation	
	--- Percent ---		--- Percent ---	Meters	Feet
Abam/Rhma-Vaal/Coca	48.3	0.3789	36.3	1 161	3,810
Abam/Rhma-Vame	44.1	.3814	22.0	1 295	4,250
Abam/Vame/Xete	20.1	.4391	25.4	1 303	4,275
Abam/Actr	18.7	.4982	44.5	1 300	4,267
Abam-Tsme/Xete	14.4	.4621	10.9	1 433	4,700

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

strong inverse correlation also exists between the interaction product of elevation and radiation index and of stocking.

These results suggest several hypotheses. The inverse correlation between radiation index and stocking could be the result of higher radiation levels during the warm season reducing seedling survival. The negative effect of elevation on stocking could be the result of several interactions. For example, the frequency of freeze-thaw cycles may increase with increasing elevation and be reflected in an increase in seedling mortality caused by frost heave.

The results of these analyses of correlation between environmental values and stocking values for habitat types are largely confirmed by an independent multiple regression analysis. In this stepwise procedure, stocking percent on each study area was the dependent variable; radiation index, elevation, slope percent, shrub cover, years since cutting, and number of regeneration operations were the independent variables. The first two factors selected were radiation index and elevation; the equation--stocking percent = 174.7 - 0.022 (elevation) - 120.1 (radiation index)--had an R of 0.72. Addition of the other four independent variables only increased the R to 0.75.

These few variables can, at best, provide only partial explanations of the mean stocking percent differences between habitat types. Too many other factors and interactions between factors are not accounted for in this study. Furthermore, the importance of environmental and treatment factors varies with habitat type (table 6); some factors have very low correlations with stocking on all habitat types (e.g., shrub cover), but other factors are highly correlated with stocking percent on one or two habitat types. The results of the analyses do suggest that the superior stocking levels on Abam/Rhma-Vaal/Coca and Abam/Rhma-Vame habitat types very possibly result from more favorable seedling environments (table 5).

Stocking Percentages of Individual Tree Species

Douglas-fir stocking is superior to that of noble fir on the Abam/Rhma-Vaal/Coca habitat type, whereas noble fir stocking is far superior to that of Douglas-fir on the Abam/Rhma-Vame, Abam/Vame/Xete, and Abam-Tsme/Xete habitat types (table 7). When subjected to paired t-tests, the differences in the stocking percentages of the two species were found to be significant on the Abam-Tsme/Xete habitat type ($p<0.05$) and on the Abam/Vame/Xete and Abam/Rhma-Vame habitat types ($0<0.01$).

The superiority of noble fir stocking over that of Douglas-fir on the Abam/Vame/Xete, Abam-Tsme/Xete, and Abam/Rhma-Vame habitat types appears to be a result of better survival in seedling environments experienced on these sites. The drastic differences in species stocking on these habitat types cannot be attributed to a lack of Douglas-fir seed for natural regeneration; stands adjacent to most of the study units of these habitat types contain an adequate seed source of both Douglas-fir and noble fir. Planting or seeding operations also fail to explain the superiority of noble fir. Records (table 8) indicate that Douglas-fir was planted or seeded as frequently as was noble fir on units in the Abam/Vame/Xete, Abam-Tsme/Xete, and Abam/Rhma-Vame habitat types and in similar numbers (discussed by Sullivan, page 44 of his thesis; see footnote 3, page 4); therefore, it appears that noble fir seedlings are simply much more able to establish themselves than are seedlings of Douglas-fir on those habitat types.

Differences Between Habitat Types in Regeneration Density

Density of tree seedlings on each habitat type (mean number of trees per acre) is shown for individual species and for all species combined in table 9. Based on an analysis of variance, differences between habitat types in both total postharvest and total advance trees are statistically significant at the 0.01- and 0.05-probability levels, respectively.

In considering mean per-acre values for all regeneration combined on the Abam/Vame/Xete, Abam-Tsme/Xete, and Abam/Actr habitat types, the reader should be aware that the trees in general are poorly distributed and that a few study units have high values which strongly influence the means (table 10).

Table 6--*Coefficient of determination (R^2) between postharvest stocking and several environmental and treatment variables*

Habitat type[1]	R^2 values between stocking and:				
	Radiation index	Shrub cover[2]	Elevation	Number of regeneration operations conducted[3]	Age of study units
Abam/Rhma-Vaal/Coca and Abam/Rhma-Vame combined	0.006	0.004	0.010	0.040	0.165
Abam/Actr	.118	.108	.524	.620	.229
Abam/Vame/Xete	.479	.123	.011	.039	.194
Abam-Tsme/Xete	.860	.058	.041	.012	.024

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

[2] For the Abam-Tsme/Xete habitat type only: shrub cover plus cover of *Xerophyllum tenax* and *Pteridium aquilinum.*

[3] Number of times the study site was planted and/or seeded.

Table 7--*Mean postharvest stocking of Douglas-fir, noble fir, and all species combined*

Habitat type[1]	All species	Douglas-fir	Noble fir
		Percent	
Abam/Rhma-Vaal/Coca	48.3	31.8	16.7
Abam/Actr	18.7	8.8	8.7
Abam/Vame/Xete	20.1	5.6	13.2
Abam/Rhma-Vame	44.1	4.8	32.1
Abam-Tsme/Xete	14.4	.2	13.6

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

Table 8--*Regeneration histories of study units*

Habitat type[1]	Planted		Seeded	
	Number	Species	Number	Species
Abam/Rhma-Vaal/Coca	6	Douglas-fir and noble fir	2	Douglas-fir and noble fir
	3	Douglas-fir	2	Douglas-fir
Abam/Actr	12	Douglas-fir and noble fir	2	Douglas-fir
	3	Douglas-fir		
Abam/Rhma-Vame	2	Douglas-fir and noble fir	0	--
Abam/Vame/Xete	3	Douglas-fir and noble fir	3	Douglas-fir and noble fir
	2	Douglas-fir		
Abam-Tsme/Xete	4	Douglas-fir and noble fir	1	Douglas-fir
	1	Noble fir		

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

Table 9--*Mean number of trees per acre by habitat type, species,*[1] *and time of regeneration*

Habitat type[1]	Total	Douglas fir	Noble fir	Pacific silver fir	Western hemlock	Mountain hemlock	Western white pine	Western redcedar	Grand fir	Lodgepole pine	Incense-cedar
						POSTHARVEST TREES					
Abam/Rhma-Vaal/Coca	1,080	626	267	115	52	--	18	--	--	--	2
Abam/Rhma-Vame	962	52	720	100	--	72	14	--	--	4	--
Abam/Vame/Xete	292	56	182	44	2	--	2	--	4	--	2
Abam-Tsme/Xete	291	2	263	8	--	18	--	--	--	--	--
Abam/Actr	272	102	114	29	16	--	5	--	6	--	--
						ADVANCE TREES					
Abam/Rhma-Vaal/Coca	402	--	--	368	25	2	--	5	2	--	--
Abam/Rhma-Vame	437	--	20	403	9	--	--	--	5	--	--
Abam/Vame/Xete	36	--	--	36	--	--	--	--	--	--	--
Abam-Tsme/Xete	35	--	11	18	--	6	--	--	--	--	--
Abam/Actr	42	--	5	30	7	--	--	--	--	--	--

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *A amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum ten* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla.*

Table 10--*Trees per acre--study unit variability*

Habitat type[1]	Mean number of trees per acre (combined total)	Study units		
		Number	With less than 300 trees per acre	With less than 100 trees per acre
Abam/Rhma-Vaal/Coca	1,482	11	0	0
Abam/Rhma-Vame	1,399	4	0	0
Abam/Vame/Xete[2]	328	8	4	3
Abam-Tsme/Xete[2]	326	7	6	2
Abam/Actr[2]	314	15	10	5

[1] Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla.*

[2] In general, trees are poorly distributed and a few study units have high values which strongly influences the means.

SEEDLING GROWTH IN RELATION TO HABITAT TYPE

In the study area, growth rates of tree seedlings are generally slow on clearcuts within the *Abies amabilis* Zone. Temperature regimes during the short growing season are considerably less than optimum (Zobel et al. 1974). Another environmental restriction on growth may be damage caused by heavy winter snowpack (Williams 1966); snowbreak can reduce the growth rates of seedlings and saplings on these habitats.

Although heights of all postharvest seedlings on the plots were determined for ages 5 and 7, only two tree species, Douglas-fir and noble fir, were sampled often enough to permit a meaningful statistical analysis of seedling growth.

Mean heights at ages 5 and 7 are clearly greatest for both Douglas-fir and noble fir on the Abam/Actr habitat type and least on the Abam/Rhma-Vame habitat type (table 11). Limited data on heights attained by Pacific silver fir seedlings in relation to habitat type suggest that they follow a similar pattern. One possible explanation of the superior height growth achieved by seedlings on clearcuts of the Abam/Actr habitat type is that southerly exposures where Abam/Actr often occurs have higher radiation loads than other habitat types, resulting in more favorable thermal environments for growth.

An analysis of variance showed the differences in mean heights of Douglas-fir on different habitat types to be significant at the 0.01-probability level for both ages. A statistical difference (at 0.01 level) in noble fir heights exists only at age 7.

Douglas-fir seedling growth clearly exceeded that of noble fir on study areas in the Abam/Vame/Xete and Abam/Actr habitat types. On the Abam/Rhma-Vame and Abam/Rhma-Vaal/Coca types there was little difference in average height of the two species, although noble fir was slightly greater than Douglas-fir. Limited height measurements on Pacific silver fir seedlings indicate that, on any given habitat type, Pacific silver fir mean height is roughly half that of Douglas-fir and noble fir seedlings of equivalent age. Overall, these data suggest that the three species rank Douglas-fir

Table 11--*Mean height*[1] *of Douglas-fir and noble fir seedlings at ages 5 and 7 on five habitat types*

Habitat type[2]	Douglas-fir age (years)		Noble fir age (years)	
	5	7	5	7
	Centimeters			
Abam/Rhma-Vame	16.4	[3]	18.6	32.3
Abam/Rhma-Vaal/Coca	21.1	36.4	23.1	37.6
Abam-Tsme/Xete	[3]	[3]	20.5	34.3
Abam/Vame/Xete	31.5	49.9	20.0	32.3
Abam/Actr	35.2	62.9	26.1	51.6

[1] Based on 485 Douglas-fir seedlings and 784 noble fir seedlings.

[2] Abam/Rhma-Vame = *Abies amabilis/Rhododendron macrophyllum-Vaccinium membranaceum;* Abam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam-Tsme/Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* Abam/Actr = *Abies amabilis/Achlys triphylla.*

[3] Deleted because of small numbers of observations.

≥ noble fir ≥ Pacific silver fir in height attained at ages 5 and 7--a ranking similar to Williams' (1968) ranking for open-grown seedlings and saplings on upper-slope clearcuts.

PLANT COMMUNITY DEVELOPMENT ON UPPER-SLOPE CLEARCUTS

Data on coverage and frequency of shrubs and selected herbs make possible some limited characterizations of plant communities 7 to 15 years after clearcutting on these upper-slope habitat types (table 12). For purposes of discussion, residual species are defined as those with at least 50-percent constancy in mature forest stands on a particular habitat type, whereas invader species are those with less than 50-percent constancy. The data for mature stand constancies are those of Dyrness et al. (1974).

Abam-Tsme/Xete Habitat Type

Successional communities on clearcuts of this habitat type are strongly dominated by herbs--mainly *Xerophyllum tenax;* shrubs will apparently not dominate these communities prior to canopy closure. Shrub cover on the seven study units averages 10.9 percent, whereas the cover of *Xerophyllum tenax* averages 32.4 percent. *Vaccinium membranaceum* average 2.1-percent cover and is the only residual shrub of any importance on the study units. Although *Xerophyllu tenax* typically dominates on this site, its cover may be less than that existing before logging.[4]

The major invading species on most study units 7 to 10 years after disturbance are a variety of grasses and sedges which tend to occupy the interstices between clumps of *Xerophyllum tenax*. The most importan invading shrub is *Ribes viscosissimum* var. *halli*, which averages 2.9-percen cover. Other shrub invaders are *Rubu leucodermis* and *Ceanothus velutinus*,

---

[4] *Xerophyllum tenax* coverage averaged 64 percent in undisturbed forest stands on the Abam-Tsme/Xete habitat type studies by Dyrness et al. (1974).

Table 12--Mean cover and frequency of [illegible]

(In percent)

Layer and species	Habitat type[1]									
	Abam/Rhma-Vaal/Coca		Abam/Rhma-Vame		Abam/Actr		Abam/Vame/Xete		Abam-Tsme/Xete	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
b layer:										
inatum	0.4	2	0	0	4.9	12	0.5	2	0.1	2/
rum	0	0	0	0	2/	2/	0	0	0	0
uata	0	0	0	0	.3	1	.1	1	0	2/
er alnifolia var. *grifolia*	0	2/	0	0	2/	2/	0	2/	.1	2/
hylos columbiana	.5	2	0.8	4	.1	1	0	0	0	0
is chrysophylla	.4	2	0	1	2/	2/	0	0	.3	2/
velutinus	4.3	14	.7	5	15.4	29	3.6	22	1.1	10
s discolor	2/	2/	0	0	.2	1	.5	2/	0	0
a myrsinites	.4	5	.4	2	1.2	12	.8	8	.5	7
arginata	.4	1	0	0	2.6	13	2.1	13	.1	1
ron macrophyllum	13.3	49	14.6	52	.1	1	0	0	0	0
ustre	0	0	.3	3	.7	5	.2	2/	2/	2/
bi	0	2/	0	0	.8	6	.2	1	0	0
cosissimum var. *halli*	.7	4	.2	2	6.1	27	6.3	34	2.9	11
codermis	2/	2/	2/	1	2/	2/	.1	1	1.8	1
viflorus	.2	1	.1	3	6.4	31	4.4	33	.2	12
ctabilis	0	0	0	0	2/	2/	0	0	0	0
iandra	0	0	0	0	0	2/	0	0	0	0
uleriana	0	0	0	0	2/	2/	.1	2/	0	0
chensis	.2	1	0	0	.1	1	.1	1	0	0
cerulea	2/	2/	0	0	.1	2/	0	0	0	0
racemosa	.4	1	.2	2	1.6	10	.5	4	.3	1
alaskaense	11.6	53	.3	3	.9	6	0	0	0	0
membranaceum	2.0	21	4.3	43	1.7	17	4.2	45	2.1	35
parvifolium	0	2/	0	0	0	0	0	0	0	0
scoparium	0	0	0	0	0	0	0	0	2/	2/
layer:										
hylos nevadensis	0	0	0	0	0	2/	0	1	.6	4
nervosa	.8	21	2/	1	.1	2	0	2/	0	0
communis	0	0	0	0	0	0	0	0	.2	1
ocarpa	.5	3	.1	1	.4	4	.4	5	.2	3
arpos mollis var. s	.2	1	.1	1	.6	3	1.3	6	.4	4
l shrub cover	36.3		22.2		44.3		25.4		10.9	
r:										
aquilinum	.7	6	1.0	8	10.2	41	11.3	55	1.6	11
m tenax	5.9	32	20.7	75	.3	3	20.4	64	32.4	78

bam/Rhma-Vaal/Coca = *Abies amabilis/Rhododendron macrophyllum-Vaccinium alaskaense/Cornus canadensis;* Abam/Rhma-Vame = *Abies amabilis/Rhododendron* *lum-Vaccinium membranaceum;* Abam/Actr = *Abies amabilis/Achlys triphylla;* Abam/Vame/Xete = *Abies amabilis/Vaccinium membranaceum/Xerophyllum tenax;* /Xete = *Abies amabilis-Tsuga mertensiana/Xerophyllum tenax.*

ess than 0.5 percent frequency or less than 0.05 percent cover.

although the *Ceanothus* occurs infrequently and is generally of low vigor.

Abam/Vame/Xete Habitat Type

The plant communities which developed after logging on this habitat type are generally herb dominated, but the shrub cover of 25.4 percent is greater than on the Abam-Tsme/Xete habitat type. *Xerophyllum tenax* averages 20.4-percent cover and is of major importance in the herbaceous layer, although its cover may be substantially less than that which existed before logging.[5] The abundance of *Pteridium aquilinum*, an invader species which averages 11.3-percent cover, is greater on the study units of Abam/Vame/Xete than on the study units of Abam-Tsme/Xete.

Vaccinium membranaceum is the dominant residual shrub, averaging 4.2-percent cover. *Ribes viscosissimum* var. *halli* (6.3-percent mean cover) and *Rubus parviflorus* (4.4-percent mean cover) are the most important invading shrubs, followed by *Ceanothus velutinus* and *Prunus emarginata*. Shrub development seems greater on study units on warmer aspects, whereas on cooler aspects *Xerophyllum tenax* and other herbaceous species are so well developed that development of a shrub-dominated community seems unlikely.

---

[5] *Xerophyllum tenax* averaged 39-percent cover in undisturbed forest stands of the Abam/Vame/Xete habitat type sampled by Dyrness et al. (1974).

Abam/Rhma-Vame Habitat Type

Plant communities on the four study units of this habitat type are poorly developed. Much mineral soil remains exposed and is unoccupied by vegetative cover, even though 10 to 15 years have elapsed since logging. Herbaceous development is limited, with the exception of *Xerophyllum tenax*, which averages 20.7-percent cover. *Rhododendron macrophyllum* (14.6-percent mean cover) and *Vaccinium membranaceum* (4.3-percent mean cover), two residual species, dominate the shrub layers of these communities. All invading shrub species are of minor importance.

Abam/Rhma-Vaal/Coca Habitat Type

Two residual species, *Rhododendron macrophyllum* and *Vaccinium alaskaense*, dominate the modest shrub layers (average 36.3-percent cover) of communities on the 11 study units established in this habitat type (table 12). The only notable invading shrub is *Ceanothus velutinus*, which occurs on slightly over half the units; *Ceanothus* is dominant on one unit and codominant on another but of little importance on the remainder.

Cornus canadensis is generally prominent in the herbaceous layer of these plant communities, as is *Xerophyllum tenax*. *Epilobium* species are important and generally abundant invading herbs.

The dominant roles played by *Rhododendron macrophyllum*, *Vaccinium alaskaense*, *Xerophyllum tenax*; and *Cornus canadensis* in these early successional communities suggest that the understory vegetation of mature forests on this habitat type tends to reconstitute itself fairly rapidly after disturbance.

Abam/Actr Habitat Type

The mean shrub cover on study units of this habitat type (44.5 percent) is the greatest encountered on the five habitat types (table 12). This is surprising since undisturbed stands on this habitat type often have poorly developed shrub layers. The mean shrub cover includes two study units with dense, vigorous stands of *Ceanothus velutinus*; even if these two units are excluded, shrub cover averages 38 percent.

Four shrub species, including three invaders, are dominants. *Ceanothus velutinus*, *Rubus parvifloru* and *Ribes viscosissimum* var. *halli* (the invaders) average 15.4-, 6.4-, and 6.1-percent cover, respectively, and the residual *Acer circinatum* averages 4.9-percent cover. Almost without exception, one of these four species is the dominant shrub on any given study unit. The constancy of two invading species, *Prunus emarginat* and *Sambucus racemosa*, and two residua species, *Vaccinium membranaceum* and *Pachistima myrsinites*, is relatively high, but these species are of seconda importance.

Herbaceous vegetation is well developed on many of the clearcut unit studied. *Pteridium aquilinum* is ofte abundant (10.2-percent mean cover) an is the dominant herb on many study uni Residual species usually present inclu *Smilacina stellata*, *Achlys triphylla*, *Asarum caudatum*, *Cornus canadensis*, and *Tiarella unifoliata*. *Epilobium* species are abundant invaders on some study units of this habitat type.

A consistent successional sequenc is not apparent. Communities on some Abam/Actr units are already shrub dominated at 7 to 15 years; others are approaching a shrub stage; and still others, which possess well-developed herb layers and poorly developed shrub layers, never will pass through a shrub-dominated phase of development.

Silvicultural Implications

The results of this study indicat that differences exist between habitat types in total stocking potential, stocking potential of individual speci height growth of tree seedlings, and development of vegetation after clearcutting. Different silvicultural approaches may, therefore, be desirabl or even necessary on different habitat types for successful regeneration. Of particular importance is the fact that many clearcuts in the *Abies amabilis* Zone of the Western Cascades of Oregon encompass two or more habitat types. Consequently, different portions (habitat types) of the same clearcut may need to be managed differently to attain maximum success in regeneration. Based on the results of this research, the following preliminary regeneration guidelines are proposed.

Abam/Rhma-Vaal/Coca Habitat Type

The clearcut system seems well suited to regeneration of forest stands on the Abam/Rhma-Vaal/Coca habitat type. This type possesses the most moderate seedling environment of all the types studied; adequate regeneration is usually achieved after clearcutting. Douglas-fir and noble fir are both suitable species for artificial regeneration. Generally, the most acute problem on clearcuts on this habitat type seems to be slow growth rates of seedlings. Low solar energy inputs during the growing season and competition between tree seedlings and shrubs may restrict seedling growth on this habitat type.

Abam/Rhma-Vame Habitat Type

This habitat type appears to behave like the Abam/Rhma-Vaal/Coca habitat type after clearcutting. Adequate regeneration is readily obtained, but established tree seedlings grow very slowly. Consequently, they are susceptible to damage from biotic agents (mammals, primarily) and damage from debris and heavy snowpack accumulations for long periods. Better stocking-level control and, perhaps, fertilization of tree seedlings may shorten this period of susceptibility.

Abam/Actr Habitat Type

This habitat type typically occurs on south- and west-facing slopes. High summer radiation, greater frequency of frost heave, rodent damage, and competition from shrubs and herbs all contribute to the poor stocking levels often observed on clearcuts on this habitat type.

The shelterwood system would seem to be an appropriate silvicultural system for stands on the Abam/Actr habitat type, provided such stands are not positioned on ridgetops or on overly steep slopes. Williamson (1973) reported that shelterwood harvesting of upper-slope Douglas-fir and mixed-conifer stands on severe sites in the Oregon Cascades is feasible and results in increased seedling establishment. If the clearcut system is used, cutting units should be kept small to ameliorate the seedling environment, and care should be taken to protect advance regeneration. Broadcast slash burning on this habitat type probably increases the severity of the seedling environment and destroys advance regeneration.

Brush development can be vigorous on some sites. When regeneration is established promptly, tree seedlings successfully compete with shrubs. On moister phases of this habitat type, dense herbaceous vegetation often develops rapidly after logging and seems to retain dominance for extended periods. This again emphasizes the need for rapid seedling establishment since the herbaceous vegetation is difficult to control once it dominates the site.

In summary, cutting systems which moderate the seedling environment and lead to prompt establishment of the new stand are particularly important on this habitat type. Seedling growth after establishment will be good.

Abam/Vame Xete Habitat Type

Although regeneration problems often follow clearcutting on this habitat type, no alternative even-aged silvicultural system may be suitable. The ridgetop or near ridgetop location of Abam/Vame/Xete sites may preclude shelterwood cutting because of a high risk of windthrow in the residual overstory. Clearcuts should generally be kept small to minimize environmental extremes and enhance natural regeneration. Large-scale site preparation methods should be avoided if possible because of potential damage to advance regeneration. Results of this study indicate that noble fir should be favored over Douglas-fir in planting operations. Brush competition is not a major regeneration problem on this habitat type.

Abam-Tsme/Xete Habitat Type

Clearcut study areas on this habitat type rarely had adequate stocking; in fact, regeneration was often nearly nonexistent. Shelterwood cutting, which would provide a less severe seedling environment, may be inappropriate because of potential losses of leave trees to wind and sun scald on the exposed ridgetops. Selection of uneven-aged management systems may also be limited by these and other factors such as steep slopes. Given all the constraints on this habitat type--low productivity (average Douglas-fir site quality V), severe regeneration problems, and limitations on suitable cutting methods--forest managers should consider a no-harvest option.

Preservation of advance regeneration is critical when the decision is made to cut on this habitat type, particularly when clearcutting is to be used. This will provide insurance if, as frequently is the case, postlogging regeneration is only slowly established. It is preferable that mineral seed beds and seedling planting sites be created by site preparation activities other than burning. Douglas-fir should not be planted on this habitat type. Since seedling establishment and subsequent growth are slow, rotations on this habitat type may have to be considerably longer than rotations envisioned for forests at lower elevations in the *Abies amabilis* Zone.

Conclusions

The results of this study demonstrate the utility of habitat types in regeneration management in the *Abies amabilis* Zone of the study area and suggest additional research, to include analyses of regeneration behavior, site index, occurrence and virulence of tree diseases, and possibly other silvicultural aspects of the whole series of Western Cascades habitat types.

Literature Cited

Cronquist, C. Leo, and Arthur Cronqui
1973. Flora of the Pacific Northwe
730 p. Univ. Wash. Press, Seattl

Daubenmire, R. F.
1959. A canopy coverage method of vegetational analysis. Northwest Sci. 33(1):43-64.

Dyrness, C. T., Jerry F. Franklin, and W. H. Moir.
1974. A preliminary classification of forest communities in the central portion of the western Cascades in Oregon. Coniferous For. Biome Bull. 4, 123 p.

Frank, Earnest C., and Richard Lee.
1966. Potential solar beam irradiation on slopes: tables for 30° to 50° latitude. USDA For. Serv. Res. Pap. RM-18, 116 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Franklin, Jerry F.
1965. Tentative ecological provinc within the true fir-hemlock fores areas of the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-22, 31 p. Pac. Northwest For. and Ra Exp. Stn., Portland, Oreg.

Franklin, Jerry Forest.
1966. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Ph. D. thesis. 132 p., illus. Wash. State Univ., Pullman.

Layser, Earle F.
1974. Vegetative classification: Its application to forestry in the northern Rocky Mountains. J. For. 72(6):354-357.

Legard, Harold A., and Leroy C. Meyer.
1973. Soil resource inventory, Willamette National Forest. USDA For. Serv. Pac. Northwest Reg., 167 p.

Peck, D. L., A. B. Grigg, H. G. Schlicker, F. G. Wells, and H. M. Dole.
1964. Geology of the central and northern parts of the western Cascade Range in Oregon. U.S. Dep. Inter. Geol. Surv. Prof. Pap. 449, 56 p.

Swanson, Frederick J., and Michael E. James.
1975. Geology and geomorphology of the H. J. Andrews Experimental Forest, western Cascades, Oregon. USDA For. Serv. Res. Pap. PNW-188, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Williams, Carroll B.
1966. Snow damage to coniferous seedlings and saplings. USDA For. Serv. Res. Note PNW-40, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Williams, Carroll B.
1968. Juvenile height growth of four upper-slope conifers in the Washington and northern Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-70, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Williamson, R. L.
1973. Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. USDA For. Serv. Res. Pap. PNW-161, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Zobel, D. B., W. A. McKee, G. M. Hawk, and C. T. Dyrness.
1974. Correlation of forest communities with environment and phenology on the H. J. Andrews Experimental Forest, Oregon. *In* Integrated research in the Coniferous Forest Biome, p. 48-56. R. H. Waring and R. L. Edmonds, eds. Coniferous For. Biome Bull. 5.

* * * * * *

GPO 986-899

Sullivan, Michael J.
1978. Regeneration of tree seedlings after clearcutting on some upper-slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Describes survival and growth of tree seedling regeneration on five upper-slope habitats in the Oregon Cascade Range. Distinct differences exist between habitat types in both stocking potential and growth.

KEYWORDS: Regeneration (artificial), forest types, vegetation types, seedling growth, logging (-regeneration, Oregon (Cascade Range), Abies amabilis.

Sullivan, Michael J.
1978. Regeneration of tree seedlings after clearcutting on some upper-slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Describes survival and growth of tree seedling regeneration on five upper-slope habitats in the Oregon Cascade Range. Distinct differences exist between habitat types in both stocking potential and growth.

KEYWORDS: Regeneration (artificial), forest types, vegetation types, seedling growth, logging (-regeneration, Oregon (Cascade Range), Abies amabilis.

Sullivan, Michael J.
1978. Regeneration of tree seedlings after clearcutting on some upper-slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Describes survival and growth of tree seedling regeneration on five upper-slope habitats in the Oregon Cascade Range. Distinct differences exist between habitat types in both stocking potential and growth.

KEYWORDS: Regeneration (artificial), forest types, vegetation types, seedling growth, logging (-regeneration, Oregon (Cascade Range), Abies amabilis.

Sullivan, Michael J.
1978. Regeneration of tree seedlings after clearcutting on some upper-slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Describes survival and growth of tree seedling regeneration on five upper-slope habitats in the Oregon Cascade Range. Distinct differences exist between habitat types in both stocking potential and growth.

KEYWORDS: Regeneration (artificial), forest types, vegetation types, seedling growth, logging (-regeneration, Oregon (Cascade Range), Abies amabilis.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: *Pacific Northwest Forest and Range*
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

CLEMSON
LIBRARY

CLEMSON UNIVERSITY LIBRARY
FEB 6 1979
SCI., TECH. & AGR. DIV

CHEMICAL COMPOSITION AND DEER BROWSING OF RED ALDER FOLIAGE

M. A. Radwan
W. D. Ellis
G. L. Crouch

Research Paper PNW-246 December 1978
Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

M. A. RADWAN is Principal Plant Physiologist with the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, [illegible]

W. D. ELLIS is a chemist with the Forest Products Laboratory, Madison, Wisconsin.

C. L. CROUCH is Principal Wildlife Biologist with the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

CHEMICAL COMPOSITION AND DEER BROWSING OF RED ALDER FOLIAGE

Reference Abstract

Radwan, M. A., W. D. Ellis, and G. L. Crouch.
1978. Chemical composition and deer browsing of red alder foliage. USDA For. Serv. Res. Pap. PNW-246, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Chemical factors suspected of influencing seasonal change in deer preference for red alder leaves were investigated. There were many differences in the leaves between seasons. It is postulated, however, that changes in contents of crude fat and total phenols were the important factors in increasing deer preference for the species from June to September.

KEYWORDS: Browse preference, foliar analysis, phenols, deer (black-tailed), *Odocoileus hemonius columbianus*, *Alnus rubra*.

RESEARCH SUMMARY

Research Paper PNW-246

1978

Selected chemical properties suspected to influence feeding preference of black-tailed deer were compared in red alder leaves obtained from one plant population in western Oregon. Leaves were collected in June when browsing was minimal and in September when utilization had begun. In general, the preferred September foliage had lower levels of moisture, acidity, crude protein, and total phenols, and higher contents of available carbohydrates and crude fat. The leaves also contained both saturated and unsaturated fatty acids commonly found in palatable plants, and fatty acid composition changed during the growing season. Despite the many differences found in leaves between seasons, it is postulated that changes in contents of crude fat and total phenols were the important factors in increasing deer preference from June to September. Because of the extreme complexity of the animal-plant relationships, however, other chemical or nonchemical differences cannot be completely ruled out as factors of preference.

Introduction

Red alder (*Alnus rubra*) is one of the most widely distributed hardwoods in the Douglas-fir region of the Pacific Northwest. Despite its abundance and easy availability in the spring and summer, alder foliage is not much utilized by black-tailed deer (*Odocoileus hemionus columbianus*) in western Washington and Oregon until early fall (Brown 1961, Crouch 1968). Although many factors may be suspected of influencing this seasonal change in deer preference, it is likely that the major deciding factor is the changing chemical composition of the foliage during the growing season. Such changes may influence preference through their effect on important foliage properties, such as nutritive value, taste, odor, and digestibility (Arnold and Hill 1972).

This paper reports chemical analyses of red alder foliage collected from one plant population in western Oregon in June when deer use of the species was minimal and again in September when browsing had begun. The analyses include both nutritional and nonnutritional chemicals suspected of influencing feeding preferences of herbivorous mammals for plants (Heady 1964, Arnold and Hill 1972, Radwan 1974), and results are discussed in relation to differences in deer browsing preference.

Materials and Methods

EAF SAMPLING

Test leaves were obtained from alder trees growing at the Tillamook Burn in northwest Oregon. Three composite samples, of approximately 500 g each, were taken in June and again in September. Each sample was obtained from about 20 healthy trees selected at random from approximately 10 acres of similar elevation, aspect, soil series, and vegetation composition. Samples were collected by clipping leaves growing within the reach of deer, and collections were made in early morning when deer commonly feed. Samples were individually placed in plastic bags and brought to the laboratory in a portable cooler.

CHEMICAL ANALYSES

In the laboratory, fresh foliage tissue was chopped into small pieces; and subsamples were taken for determination of dry matter, pH, and total phenols. Remaining tissue was dried to constant weight at 65° C, ground to 40 mesh in a Wiley mill, and stored in closed containers at -15° C until used for other analyses.

Moisture content was determined by drying to constant weight in a forced-air oven at 65° C, and ash in the ground tissue was estimated by heating in platinum crucibles at 500°-550° C for 4 hours. Hydrogen-ion concentration (pH) was determined with glass electrode on aqueous extracts obtained by homogenizing fresh tissue in recently boiled distilled water. Total phenols, obtained by extraction in Soxhlet apparatus with 80-percent methanol, were estimated by using the Folin-Denis reagent according to the procedure of Swain and Hillis (1959); and tannic acid was used as the reference standard. Total available carbohydrates were extracted and hydrolyzed with 0.2 N H_2SO_4 (Smith et al. 1964), and resulting sugars were determined as glucose by the ceric sulfate method (Hassid 1937).

For fatty acid analyses, lipids were extracted with petroleum ether (b.p. 30°-60° C) in Soxhlet, saponified with methanolic NaOH, and methylated with BF_3 in methanol (Metcalfe et al. 1966, Horwitz 1970). Resulting fatty acid methyl esters were taken up in heptane and analyzed with a gas chromatograph equipped with flame ionization detector and a 3-m x 3-mm (ID) stainless steel column packed with 10-percent diethylene glycol succinate (DEGS) on 80- to 100-mesh Chromosorb W (AW-DMCS). Operating conditions were: injection port, 225° C; detector, 225° C; column, isothermal at 190° C; and H_2, N_2, and air flows of 25, 30, and 250 ml/minute, respectively. Heptadecanoic acid (17:0), added to samples prior to esterification, was used as an internal standard. Resolved peaks were identified by comparing unknowns' relative retention times with those of known compounds and by peak enrichment; and compounds were quantified by measuring peak areas with electronic integrator.

Analyses of other tissue components were made as follows: total nitrogen by the micro-Kjeldahl technique, and crude fat from loss in tissue weight after extraction with ether in Soxhlet (Horwitz 1970); nitrate by the phenoldisulfonic acid method (Johnson and Ulrich 1950); and acid-detergent fiber and acid-detergent lignin according to Van Soest (1963).

All analyses were made in duplicate on each of the three replicate samples, and mean values for the two leaf collections were compared.

Results

The average chemical characteristics of the leaf tissues of red alder collected at two different times during the year are summarized in table 1. Relative acidities are shown in pH units, and concentrations of the different chemical constituents are expressed on dry weight basis.

Differences among leaves of the two collections were apparent in most properties studied, but the magnitude of the differences and the direction of change varied with the property in question. Brief consideration of the individual properties follows.

Table 1--*Chemical properties of red alder foliage collected at two different times during the year*[1/]

Chemical property	Unit of measure	Collection date of foliage	
		June 1974	September 1974
Moisture	percent	67.69	58.67
Ash	percent	2.82	3.49
H-ion concentration	pH	4.60	5.55
Acid-detergent fiber	percent	21.80	20.69
Acid-detergent lignin	percent	12.48	10.86
Total available carbohydrates	percent	10.43	12.31
Total nitrogen	percent	2.38	1.83
Nitrate nitrogen	ppm	68.00	62.00
Total phenols	percent	10.22	5.13
Crude fat	percent	3.52	7.86

[1/] Values are averages of three composite samples each. Total phenols are expressed as tannic acid equivalents.

Moisture.--Moisture was the highest of all constituents determined; the average moisture content for all leaves was approximately 63 percent. There was a decrease in moisture content as dry matter accumulated during leaf maturation. Consequently, leaves were less succulent in September than in June.

Minerals.--Mineral elements, as shown by the ash content, averaged about 3 percent for the two collections. This indicates that an average of approximately 97 percent of the dry matter was organic in nature. The ash content increased from June to September reflecting increased absorption of minerals as the season progressed. Difference between the two collections, however, was small.

Acidity.--The pH of the leaves increased during the growing season; it ranged from 4.60 in June to 5.55 in September. Leaves, therefore, were less acidic during the period of deer browsing.

Fiber and lignin.--The acid-detergent fiber, representing the acid insoluble cell-wall materials (Van Soest 1965), was, as expected, the highest of the measured organic constituents of the leaves. The fiber decreased slightly from June (21.80 percent) to September (20.69 percent).

Trends of acid-detergent lignin were similar to those of the fiber. Lignin content for both collections averaged 11.67 percent of dry matter.

Available carbohydrates.--Total available carbohydrates averaged over 1 percent in the leaf tissues. Clearly, available carbohydrates constituted a major nutritional component of the leaves' organic matter. Also, as expected, carbohydrate levels were higher in September (12.31 percent) than in June (10.43 percent).

Nitrogen.--Total nitrogen ranged from a high of 2.38 percent in June to a low of 1.83 percent in September. For comparison with other data in the literature, these nitrogen levels are equivalent to approximately 14.9 and 11.4 percent crude protein, respectively. Red alder leaves, therefore, are characterized by high levels of protein. In both the June and September leaves, crude protein was much higher than the minimum requirement for black-tailed deer as proposed by Einarsen (1946).

Nitrates were low, averaging 65 ppm for the two collections. Also, both the June and September leaves contained similar amounts of nitrates.

Phenols.--Total phenols ranged from 10.22 percent in June to 5.13 percent in September. This decrease by approximately 50 percent was the greatest noted among the leaf components which declined during the growing season. The reduced phenolic content also coincided with the period of increased deer browsing.

Fat.--The average crude fat content of leaves substantially increased during the growing season; the September value (7.86 percent) was more than twice that of the June concentration (3.52 percent). Such an increase must have greatly enhanced the caloric content of the September leaves since crude fat is a high energy source.

Fats were studied further by hydrolysis and analysis of their component fatty acids by gas-liquid chromatography.

Fatty acids.--The main fatty acids of red alder leaves were lauric, myristic, palmitic, stearic, oleic, linoleic, and linolenic (table 2). In both the June and September leaves, saturated acids predominated over unsaturated compounds. Also, in all leaves, palmitic was the most abundant (over 47 percent), followed by linolenic (22.0, 30.8 percent); lauric had

Table 2--*Percentage composition of foliar fatty acids of red alder*[1]

Fatty acid		Collection date of foliage	
		June 1974	September 1974
Lauric	12:0	0.2	0.6
Myristic	14:0	3.4	5.4
Palmitic	16:0	47.7	47.4
Stearic	18:0	7.3	3.8
Oleic	18:1	4.9	3.8
Linoleic	18:2	14.6	8.4
Linolenic	18:3	22.0	30.8

[1] Numbers following fatty acids indicate number of carbon and number of double bonds, respectively. Percents are averages of three composite samples each.

the lowest concentrations (0.2, 0.6 percent). During the growing season, levels of lauric, myristic, and linolenic increased, whereas those of stearic, oleic, and linoleic decreased; palmitic concentrations remained unchanged.

Discussion and Conclusions

Results show that in June when utilization by deer was minimal, red alder leaves contained adequate levels of minerals, available carbohydrates, protein, and fats to satisfy the nutritional needs of herbivores, including deer (Maynard 1951). The leaves were also succulent, moderately acidic, had enough roughage as shown by the contents of fiber and lignin, and contained nontoxic levels of nitrates as well as fatty acids which are usually found in palatable plants. The total phenols in the leaves, however, were quite high; they amounted to over 10 percent of the dry matter and greatly exceeded levels found in plants browsed by black-tailed deer in winter (Radwan and Crouch 1974).

Comparison of the June and September leaves indicated many variations in most chemical constituents. Thus, as leaves grew older and became more preferred by deer in September, moisture, acidity, protein, and phenols had decreased, while available carbohydrates and fats were increased. Fatty acids also changed in their composition during the same period of time. Obviously, it is impossible to state which change or combination of changes were actually responsible for the increased preference or the mechanism by which any of these factors were operating. One may speculate, however, that changes in fats and phenols were the important factors. That changes in these two leaf constituents were much greater than those shown by remaining constituents tends to support this speculation. Crude fat also is recognized as a high energy food source for animals, and associations of high fat contents in forages with high preference by some animals have been eported (Hardison et al. 1954, Louw t al. 1967). Phenols, on the other and, have been generally considered s defense compounds which protect lants from their natural enemies, ncluding herbivores (Levin 1971). urthermore, tannins, which are stimated here as total phenols, ave been shown to reduce palatability and digestibility of some lants in ruminants (Wilkins et al. 953, Donnelly and Anthony 1973); nd their great decline in September ould very well account for the increased utilization of the leaves in ne fall.

Factors affecting animal preferences for plants are extremely varied nd complex. Accordingly, we recognize nat chemical constituents other than nose reported here or nonchemical actors such as differences in availbility of preferred food may have nfluenced deer preference.

Literature Cited

rnold, G. W., and J. L. Hill.
1972. Chemical factors affecting selection of food plants by ruminants. *In* Phytochemical ecology. Proc. Phytochem. Soc. Symp. No. 8, p. 71-101. Academic Press Co., New York.

rown, E. R.
1961. The black-tailed deer of western Washington. Wash. Dep. Game, Biol. Bull. 13, 124 p. Olympia, Wash.

rouch, G. L.
1968. Forage availability in relation to browsing of Douglas-fir seedlings by black-tailed deer. J. Wildl. Manage. 32:542-553.

nnelly, E. D., and W. B. Anthony.
1973. Relationship of *Sericea lespedeza* leaf and stem tannic to forage quality. Agron. J. 65:993-994.

Einarsen, A. S.
1946. Crude protein determinations of deer food as an applied management technique. Trans. N. Am. Wildl. Conf. 11:309-312.

Hardison, W. A., J. T. Reid, C. M. Martin, and P. G. Woolfalk.
1954. Degree ot herbage selection by grazing cattle. J. Dairy Sci. 37:89-102.

Hassid, W. Z.
1937. Determination of sugars in plants by oxidation with ferricyanide and ceric sulfate titration. Ind. Eng. Chem. (Anal. Ed.) 9:228-229.

Heady, H. F.
1964. Paltability of herbage and animal preference. J. Range Manage. 17:76-82.

Horwitz, W., ed.
1970. Official methods of analysis. Assoc. Off. Anal. Chem., Ed. 11, 1,015 p. Washington, D.C.

Johnson, C. M., and A. Ulrich.
1950. Determination of nitrate in plant material. Anal. Chem. 22:1526-1529.

Levin, D. A.
1971. Plant phenolics: an ecological perspective. The Am. Nat. 105:157-181.

Louw, G. N., C. W. P. Steenkamp, and E. L. Steenkamp.
1967. Relationship between the ether extract content of Karoo shrubs and their palatability to sheep. South Afr. J. Agric. Sci. 10:867-873.

Maynard, L. A.
1951. Animal nutrition. 474 p. McGraw-Hill Inc., New York.

Metcalfe, L. D., A. A. Schmitz, and J. R. Pelka.
1966. Rapid determination of fatty acid esters from lipids for gas chromatographic analysis. Anal. Chem. 38:514-515.

Radwan, M. A.
1974. Natural resistance of plants

to animals. *In* Wildl. and For. Manage. in the Pac. Northwest Symp. Proc., p. 85-94. Oreg. State Univ. Press, Corvallis.

Radwan, M. A., and G. L. Crouch.
1974. Plant characteristics and deer feeding preference. J. Wildl. Manage. 38:32-41.

Smith, D., G. M. Paulson, and C. A. Raguse.
1964. Extraction of total available carbohydrates from grass and legume tissue. Plant Physiol. 39:960-962.

Swain, T., and W. E. Hillis.
1959. The phenolic constituents of *Prunus domestica*. I. The quantitative analysis of phenolic constituents. J. Soc. Food Agric. 10:63-68.

Van Soest, P. J.
1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Off. Chem. 46:829-832.

Van Soest, P. J.
1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834-843.

Wilkins, H. L., R. P. Bates, P. R. Henson, I. L. Lindahl, and R. E. Davis.
1953. Tannin and palatability in *Sericea lespedeza* L. Cuneata. Agron. J. 45:335-336.

Radwan, M. A., W. D. Ellis, and G. L. Crouch.
1978. Chemical composition and deer browsing of red alder foliage. USDA For. Serv. Res. Pap. PNW-246, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Chemical factors suspected of influencing seasonal change in deer preference for red alder leaves were investigated. There were many differences in the leaves between seasons. It is postulated, however, that changes in contents of crude fat and total phenols were the important factors in increasing deer preference for the species from June to September.

KEYWORDS: Browse preference, foliar analysis, phenols, deer (black-tailed), *Odocoileus hemonius columbianus*, *Alnus rubra*.

Radwan, M. A., W. D. Ellis, and G. L. Crouch.
1978. Chemical composition and deer browsing of red alder foliage. USDA For. Serv. Res. Pap. PNW-246, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Chemical factors suspected of influencing seasonal change in deer preference for red alder leaves were investigated. There were many differences in the leaves between seasons. It is postulated, however, that changes in contents of crude fat and total phenols were the important factors in increasing deer preference for the species from June to September.

KEYWORDS: Browse preference, foliar analysis, phenols, deer (black-tailed), *Odocoileus hemonius columbianus*, *Alnus rubra*.

Radwan, M. A., W. D. Ellis, and G. L. Crouch.
1978. Chemical composition and deer browsing of red alder foliage. USDA For. Serv. Res. Pap. PNW-246, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Chemical factors suspected of influencing seasonal change in deer preference for red alder leaves were investigated. There were many differences in the leaves between seasons. It is postulated, however, that changes in contents of crude fat and total phenols were the important factors in increasing deer preference for the species from June to September.

KEYWORDS: Browse preference, foliar analysis, phenols, deer (black-tailed), *Odocoileus hemonius columbianus*, *Alnus rubra*.

Radwan, M. A., W. D. Ellis, and G. L. Crouch.
1978. Chemical composition and deer browsing of red alder foliage. USDA For. Serv. Res. Pap. PNW-246, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Chemical factors suspected of influencing seasonal change in deer preference for red alder leaves were investigated. There were many differences in the leaves between seasons. It is postulated, however, that changes in contents of crude fat and total phenols were the important factors in increasing deer preference for the species from June to September.

KEYWORDS: Browse preference, foliar analysis, phenols, deer (black-tailed), *Odocoileus hemonius columbianus*, *Alnus rubra*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

n D. Bevins &
rt E. Martin

CLEMSON
LIBRARY

LIBRARY
MAR 12
TECH & AGR. DIV

An Evaluation of the Slash (I) Fuel Model of the 1972 National Fire Danger Rating System

earch Paper PNW - 247 December 1978
cfic Northwest Forest and Range Experiment Station
Department of Agriculture Forest Service

AUTHORS

COLLIN D. BEVINS is Research Director of Systems for Environmental Mañagement, Inc., P.O. Box 3776, Missoula, Montana 59806. ROBERT E. MARTIN is Project Leader, Silviculture Laboratory, USDA Forest Service, Bend, Oregon.

Contents

INTRODUCTION 1
STUDY APPROACH 1
SENSITIVITY ANALYSIS 2
FUEL LOAD ESTIMATES 4
FUEL LOAD PARAMETERS 7
FINE FUEL SURFACE AREA-TO-VOLUME RATIO 8
FUEL BED DEPTH 9
GENERAL PARAMETER VALUES 10
FUEL MODEL PERFORMANCE 11
DISCUSSION 13
CONCLUSIONS AND SUMMARY 15
LITERATURE CITED 16

ACKNOWLEDGMENTS

We gratefully acknowledge support of the National Fire Danger Rating System project. We also extend our appreciation to the various Regions, National Forests, Ranger Districts, the Northern Forest Fire Laboratory, and other Forest Service units for supplying research data.

AN EVALUATION OF THE SLASH (I) *FUEL MODEL OF THE 1972 NATIONAL FIRE DANGER RATING SYSTEM*

Reference Abstract

Bevins, Collin D., and Robert E. Martin.
1978. An evaluation of the slash (I) fuel model of the 1972 National Fire Danger Rating System. USDA For. Serv. Res. Pap. PNW-247, 17 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The slash (I) fuel model of the 1972 National Fire Danger Rating System was evaluated for homogeneity within the model and for differences from other fuel models. Clearcut slash is different from partial cut slash at the 1-percent level of confidence. Pacific Northwest clearcut slash loads are different from other clearcut slash at the 5-percent level. New fuel models are proposed.

KEYWORDS: Fire danger rating, slash, fire behavior (Forest), fuels (forest fire), models.

RESEARCH SUMMARY

Research Paper PNW-247

1978

The slash (I) fuel model of the 1972 NFDRS was evaluated with respect to the specific fuel parameters in comparison to measured values in the field. Proposals are made for new fuel models. Statistical comparison at the present level indicate two western slash fuel models would be better, one representing clearcut slash, the other partial cut slash. If the 5-percent level of significance is used, separate clearcut slash loads should be used for Pacific Northwest clearcuts and other western clearcuts. The proposed clearcut model has selected load values similar to the slash (I) fuel model, and loads for the partial cut model are only 68 percent of the clearcut model. Packing ratios are higher than in the I model.

Introduction

The National Fire Danger Rating System (NFDRS), implemented in 1972, is a two part system based upon fire occurrence and fire behavior indices. Fire occurrence is a function of the ignition probability and prevalence of ignition sources, but fire behavior depends upon the relative rate of fire spread, energy release, and flame length (Schroeder et al. 1972). The 1972 NFDR System was developed at the Rocky Mountain Forest and Range Experiment Station of the USDA Forest Service, Fort Collins, Colorado, beginning in the spring of 1968. At that time the projected operational target date was set for 1972. The target date was met and a summary publication was made available in February of that year (Deeming et al.1972). A more complete history of the conception and implementation of the NFDRS is given by Deeming and Brown[1] and Deeming and Lancaster (1971).

The fire behavior portion of the NFDRS is based upon a mathematical fire spread and intensity model developed at the Northern Forest Fire Laboratory of the USDA Forest Service, Missoula, Montana (Rothermel 1972). This model requires several inputs for its solution. A number of these inputs are fuel parameters that describe the wildland fuel situation, and as a set are referred to as a fuel model. Nine such fuel models are currently used by the NFDRS to represent all wildland fuel situations in the U.S. In the construction of the NFDRS fuel models, an attempt was made to use modal values of fuel descriptors characterizing the typical fuel complex to be represented. Data, however, on many of the fuel parameters were either scarce or nonexistent, and in many instances selection of the model parameter values was based upon a combination of objective and subjective observations and estimates. Furthermore, the number of models to be used was determined from a consensus of opinion rather than an analysis of fuel type range and variance (Deeming and Brown 1972). These difficulties were unavoidable due to lack of time before the 1972 implementation date.

The NFDRS project has sought more objective and quantitative evaluation of the System's fuel models. The grass fuel model was evaluated first, and a methodology for evaluating fuel models was established (Sneeuwjagt 1974). The objective of the study reported here was to evaluate the activity-created slash (I) model of the NFDRS. The results of the study would be used in development of fuel models for the 1978 version of the NFDRS.

Study Approach

The 1972 NFDRS incorporates a single fuel model to characterize all western conifer clearcut slash fuels. This fuel type is represented by the System's slash (I) fuel model, whose general and specific parameters are shown in table 1. The general parameters have a constant value for all nine fuel models due to either a low natural variability between fuel types, or the fire model's insensitivity to them (Deeming and Brown 1972). The specific parameters vary from one fuel model to the next, and include the fuel load by size class, the fuel bed depth, and the fine fuel's surface-area-to-volume ratio.

Meeting the objective of the study involved addressing the following questions.

(1) Are all clearcut slash fuel situations members of the same statistical population, regardless of activity-type or physiographic location, or do they occur in several distinct populations?

(2) Is the clearcut slash fuel population(s) statistically different from the other eight fuel model populations, particularly the G fuel model which represents natural dead and down fuels under a dense conifer canopy?

---

[1] Deeming, J. E., and J. K. Brown. 1972. Fuel models of the National Fire Danger Rating System. USDA For. Serv. Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo. (Unpublished).

fuel bed depth is used to derive the fuel array's packing ratio, which in turn is used in most of the fire model's intermediate calculations. Since FIREMOD and the NFDRS Spread Components weight input parameters by the surface area contribution of each fuel size class, we would also expect the fine fuel parameters of load, moisture content, and surface-area-to-volume ratio to exert a strong influence on the model's prediction.

Fuel Load Estimates

Data for the analysis of the fuel load parameters for the 1-, 10-, and 100-hour timelag fuel size classes of the I and G fuel models originated from two sources. The first source is data we collected by planar intersect inventories on 31 stands in Region 6 subjected to various stand treatments. The second source is data from Forest Service Regions 1, 3, 5, 6, and 10, solicited from Regional, Forest, and District offices. Only those stand inventories compiled using the planar intersect technique (Brown 1974) were used in the analysis. A total of 235 activity-created fuel inventories and 122 natural dead and down fuel inventories were collected (table 3). Of the activity-created fuel inventories, 144 were in clearcut slash.

The load data were quantitatively analyzed by performing a series of one way analyses of variance (ANOVA) on several data groupings, allowing for a test of the number of distinct fuel load populations.

Certain assumptions inherent in the ANOVA process have to be made to maintain statistical validity. First, it is necessary to assume the collected data constitute a random sample of all western slash areas. This assumption is necessarily false to an unknown degree since this type of data exists in limited amounts in limited areas, but an attempt was made to gather as much of it as possible for the analysis. The data may deviate from randomness because of a tendency for field offices to sample the heavier, more hazardous stands in the protection unit rathe than gather a random sample from th entire range of loading situations. The results would give heavier fuel load estimates. Also, fuel load inventory is much more common in Regions 1 and 6 than elsewhere, so more data exist for these areas. The second statistical assumption is that the populations of fuel loads are normally distributed and homogeneous in variance for each fuel type and each size class.

Other assumptions of a nonstatistical nature have to be made to provide a starting point for the ANOVA. We first assumed that the load data can be divided into smalle groups based upon two stratifications first, the type of activity that created the slash, and second, the physiographic location of the stand. In the first category, four activit types are initially recognized--clearcutting, precommercial thinning, other partial cutting methods (overstory removal, sanitation cuts, shelterwood cuts, etc.), and natural dead and down fuels (no activity). In the second category, only two physiographic groups are recognized. The first includes all the data fro the west side of the Oregon and Washington Cascade crest and the southeastern forests of Alaska wher the precipitation is very high and the winters are mild. Data from th coast of northern California could also be part of this group, but non were available in this study. The second assumed physiographic population consists of data from all other areas of the Western United States.

We first conducted an ANOVA between the two physiographic groupings to test for significant differences in means of fuel loads. An ANOVA was then run on the four activity-type groups, comparing (1) thinning data with other partial cut data, (2) thinning plus partial cut data against clearcut data, and finally (3) natural dead and down fuel data versus any of the other treatments. The stepwise procedure was repeated for the fuel load data of each size class of woody fuel to allow for the progressive consolidat

Table 3--Fuel load inventory data sources[1]

Source	Type of slash fuel inventoried							
	Clearcut	Thinning	Partial cut	Overstory removal	Sanitation	Shelterwood	Select cut	Natural
	- - - - - - - - - - - - - - - - Number of inventories - - - - - - - - - - - - - - - - -							
Region 1								
Northern Forest Fire Laboratory	21							
Clearwater National Forest	9			6	9			4
Regional Office	25	6	4	4	1	5		
St. Regis National Forest, St. Regis Ranger District	1	15		3		2		
Panhandle National Forest								100
Region 2								
Regional Office	11	7	1				4	
Region 3								
Regional Office	12							
Region 5								
Modoc National Forest, Doublehead Ranger District	2	4	3					4
Region 6								
Bevins (1975)	24	5	1					1
Schmidt (1975)	14	3						6
Swanson (1974)	1							7
Regional Office	4	4	4					
Region 10								
Regional Office	20							

---

[1] All fuel loadings used were measured by the planar intersect method (Brown 1974).

of smaller, assumed groupings into larger, statistically alike populations, until one or more distinct fuel distributions emerged. When combined, the distinct populations (or population) should cover the entire continuum of the western slash fuel loading and serve as a test of the 1972 NFDRS' implicit assumption that a single fuel model can adequately define all western conifer clearcut fuel situations. In processing the screen this way, we have possibly increased the probability of obtaining a significant difference among fuel groups.

The two assumed physiographic populations were not statistically different at the 1-percent level of significance (tables 4 and 5). They did exhibit considerable differences in 10- and 100-hour fuels but not in the 1-hour fuel. In keeping with the NFDRS aim to use a minimal satisfactory number of fuel models, the analysis was continued, assuming no difference between the two physiographic provinces. More extensive sampling might indicate significant differences between the two populations. Within the activity-type category, the thinning and partial cut populations are also found indistinct from each other at the 1-percent level for all three fuel size classes and were consolidated into a single partial cut data group. This consolidated population is significantly different at the 1-percent level from the clearcut fuel population for the 1- and 100-hour size classes but not for the 10-hour class. Finally, the natural dead and down fuel loads are distinct from all activity-created fuel loads, except in the 1-hour size class where it is not different from the clearcut population.

From these results, it appears that two distinct slash fuel load

Table 4--Fuel loads and standard deviations of the 1-, 10-, and 100-hour timelag classes of woody fuels for activity slash and natural down and dead fuels

Population	Mean	SD
	- - - - kg/m^2	- - - -
1-hour fuels		
Clearcut (Pacific Northwest)	0.214	0.116
Other clearcut	.255	.187
All clearcut	.242	.167
Partial cut	.119	.067
Natural	.243	.223
10-hour fuels		
Clearcut (Pacific Northwest)	.632	.429
Other clearcut	.912	.781
All clearcut	.789	.662
Partial cut	.749	.424
Natural	.318	.211
100-hour fuels		
Clearcut (Pacific Northwest)	1.706	.723
Other clearcut	1.417	.794
All clearcut	1.543	.774
Partial cut	1.234	.746
Natural	.638	.397

Table 5--Analysis of variance of fuel loads among various categories of cutting and natural down and dead fuel loadings

Treatments	F(DF)[1]		Significance level (percent)
1-hour fuels			
Thinning vs. partial cut	1.19	(1, 50)	NS[2]
Clearcut vs. partial cut	24.96	(1, 22)	99.5
PNW clearcut vs. other clearcut	.95	(1, 70)	NS
Natural vs. clearcut	.00	(1, 192)	NS
10-hour fuels			
Thinning vs. partial cut	3.17	(1, 90)	90
Clearcut vs. partial cut	.27	(1, 234)	NS
PNW clearcut vs. other clearcut	6.602	(1, 142)	97.5
Natural vs. partial cut	95.16	(1, 212)	99.5
100-hour fuels			
Thinning vs. partial cut	4.51	(1, 90)	90
Clearcut vs. partial cut	9.21	(1, 234)	99
PNW clearcut vs. other clearcut	5.09	(1, 142)	95
Natural vs. partial cut	56.62	(1, 212)	99

[1] F = F ratio, DF = degrees of freedom.

[2] NS = not significant at 90-percent level.

populations exist along the fuel load continuum, both of which are unlike the natural dead and down fuel situation characterized by the G fuel model (see footnote 1). These two slash fuel load populations correspond to clearcut treatments and all partial cut treatments.

Fuel Load Parameters

Values for the load parameters of the two activity-created slash fuel models were selected based upon the NFDRS' "average-bad" philosophy (Deeming and Lancaster 1971). Under this philosophy, each fuel model should be equal to or overestimate most of the fuel load situations it is modeling. That is, instead of using a mean load value where 50 percent of the real world fuel loads are underestimated by the model, a higher value should be chosen that would reduce this underestimation. The critical level chosen, however, should overestimate most of the fuel load situations, yet be located near the mean of its distribution curve. If the selected value lies too far out into the right tail of the curve, it is no longer representative of that population. Under these criteria, fuel load values were selected from the 67 percent of the population's normal distribution curve. This value should represent the entire population while overestimating two-thirds of the actual fuel load situations.

Under the assumption of a normal distribution, the 67-percent frequency level value was derived by:

$$\text{67-percent level} = \bar{\omega} + 0.44\, s_{\omega} \; ; \quad (1)$$

where, $\bar{\omega}$ is the fuel size class mean load and s_{ω} is its standard deviation.

Table 6 summarizes the 50-percent critical level (mean), standard deviation, and 67-percent critical level for the three size classes of the clearcut and partial cut load populations.

Table 6--Mean, standard deviation, and selected fuel loading values for 1-, 10-, and 100-hour timelag fuel classes from clearcut, partial cut, and natural down and dead situations

Fuel type	Needles	1-hour			10-hour			100-hour		
	67%	50%	SD	67%	50%	SD	67%	50%	SD	67%
	Kilograms/meter^2									
Clearcut	0.545	0.242	0.167	0.315	0.789	0.662	1.080	1.543	0.774	1.885
Partial cut	.260	.119	.007	.150	.749	.442	.935	1.234	.745	1.560
Natural	--	.243	.223	--	.318	.211	--	.638	.397	--

Needle loading.--Needle loads should be included in the fuel loads for the 1-hour size class since the NFDRS considers "average-bad" conditions. Because many slash units are not treated until after the very flammable "red slash" stage, adding the needle component makes a closer approximation to the potential fire behavior.

The needle loading value was taken from Fahnestock's (1960) ratios of needle weight to 1-hour size class branch wood weight (r) for live crowns of three common timber species as tabulated below.

Species	r values
Lodgepole pine (*Pinus contorta* Dougl.)	1.34
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	2.25
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	1.59
Average	1.73

The average value for r is 1.73, and needles therefore contribute an extra 173 percent to the 1-hour fuel loads and make up 63.4 percent of the total 1-hour fuel load in partial and clearcut slash.

Fine Fuel Surface Area-to-Volume Ratio

The fine fuel surface area-to-volume ratio (σ_1) is another fuel model specific parameter, and for the slash fuel models, has to be representative of both the needle and woody branch wood components. The range of σ_1 is therefore very large, from 99.8 cm^{-1} for western hemlock needles (Brown 1970a) to 11.8 cm^{-1} for lodgepole pine twigs (Brown and Roussopoulos 1974). Values in table 7 for σ of four common slash species' needles, 1-, 10- and 100-hour fuels were derived from mean particle diameter data by

$$\sigma = 4 / \bar{d}; \qquad (2)$$

where, d is the mean particle diameter in centimeters, and the particles are assumed to be cylindrical in shape with negligible surface area on the ends.

The average for needles of the conifer slash species is 72.8 cm^{-1}, and 18.3 cm^{-1} for the 1-hour branchwood. The needle component receives a weighting factor of 0.634 based upon its mass contribution to the 1-hour size class fuel loading, and the woody component's σ is weighted by 0.366. The resulting weighted surface area-to-volume ratio for the fines, σ_1, is 52.8 cm^{-1}. This value is 7.3 percent greater than the current NFDRS value of 49.2 cm^{-1}. The sensitivity analysis indicates that use of the new value of 52.8 cm^{-1} will increase the rate of spread prediction by only 4.7 percent. Given the wide range of values and

Table 7--Surface area-to-volume ratios for common conifer slash species

Species	Needles (cm^{-1})	1-hour (cm^{-1})	10-hour (cm^{-1})	100-hour (cm^{-1})
Ponderosa pine	57.6[1]	--	2.96[2]	0.98[2]
Lodgepole pine	64.74[1]	11.8[2]	3.23[2]	.89[2]
Douglas-fir	69.1[1]	15.4[2]	3.23[2]	.98[2]
Western hemlock	99.8[1]	27.6[3]	2.80[3]	.90[3]
Average	72.8	18.3	3.06	.94

[1] Brown (1970a).

[2] Brown and Roussopoulos (1974).

[3] Bevins (1978).

the weighting method used, the small difference between the selected and NFDRS values, and the resolution required by the System, we feel that the current NFDRS value of 49.2 cm^{-1} is acceptable and representative of fine slash fuels.

Fuel Bed Depth

An ANOVA of the highest particle intersect fuel bed depth data was performed for the clearcut treatments versus the partial cut types, and the two populations were found to be different at the 1-percent significance level. The highest particle intersect depths were used since they are part of the standard planar intersect inventory method (Brown 1974) and are included in most of the collected inventory data.

Because the vertical distribution of logging slash is not uniform (Brown 1970b, Bevins 1975), use of the highest particle intersect depth tends to overestimate the fuel bed depth and underestimate the bed's bulk density and packing ratio. A more accurate and appropriate depth value is the bulk depth, the depth through which the bulk density of the fuel array is maintained (Frandsen 1974). An empirical relationship has been established between the bulk depth and the highest particle intersect depth based upon duplicate depth measurements taken at the same point using both techniques. A limited number of areas were sampled and may be very weak in representing non-clearcut areas. The data for the relationship were collected from 24 clearcuts, 5 precommercial thinnings, 1 partial cut in a regeneration unit, and a natural dead and down area. The relationship between the two depths is:

$$\text{Bulk Depth (cm)} = 2.26 + 0.52 \text{ Highest Intersect depth (cm)}. \quad (3)$$

The r^2 of the relationship is 0.83. The standard error of the estimate is only 3.51 centimeters, or 18.5 percent. We believe the equation to be both accurate and precise enough to reduce the highest particle intersect depths to bulk depths.

The 67-percent levels of the two fuel type bulk depths were derived using equations (1) and (3). Use of the 67-percent value maintains the convention previously used in the derivation of the fuel load values, raises the fuel bed depths nearer to their optimum levels, and upholds the NFDRS' "average-bad" philosophy. The resulting values are 32 centimeters for clearcut slash, and 15 centimeters for the partial cut slash model (table 8). Both values are significantly lower

Table 8--Highest intersect and bulk depths for partial and clearcut slash

Fuel type	Highest intersect mean	Standard deviation	Estimated bulk depth mean	Bulk depth 67th percentile
	Centimeters			
Clearcut	43.4	26.2	20.3	31.8
Partial cut	22.2	12.3	9.3	14.7

than the current NFDRS bed depth for slash of 106.7 centimeters.

General Parameter Values

Low heat of combustion.--Mean values for the low heats of combustion for five major slash species have an average value of 19 992 joules/gm (table 9), 7.5 percent higher than the current NFDRS value of 18 603 j/g. This produces a 7.5-percent increase in the rate of spread prediction, a 15-percent increase in the fireline intensity, and a 7-percent increase in flame length. Because the low heat of combustion of conifers seldom drops below 18 603 j/g, and because of the fire model's sensitivity to this parameter, it is recommended that it be included as a specific parameter in the two proposed slash models with a value of 20 000 j/g.

Particle density.--The sensitivit analysis indicates that the fuel particle density would have to drop from 0.513 g/cm^3 to 0.330 g/cm^3 or increase to 0.696 g/cm^3 to effect a 5-percent change in the fire model rate of spread prediction. Due to this low fire model sensitivity and the restricted range of conifer slash wood densities, the current value of 0.513 g/cm^3 is acceptable.

Table 9--Low heat of combustion for five common conifer slash species

Species	Low heat of combustion	Source
	Joules/gm	
Ponderosa pine (*Pinus ponderosa* Laws.)	20 930	Brown 1972
Lodgepole pine (*Pinus contorta* Dougl.)	18 921[1]	Corder 1973
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	20 386	Brown 1972
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	18 460[1]	Corder 1973
Western redcedar (*Thuja plicata Donn*)	21 265[1]	Corder 1973
Average	19 992	

[1] Adjusted from high to low value by subtracting 5 434 joules/gm.

Total mineral content.--Similarly, the total mineral content would have to change by more than an order of magnitude to effect a 5-percent change in the fire model behavior predictions. The current value of 0.055 fraction odw is close to Philpot's (1970) values for ponderosa pine needles (0.039) and white pine needles (0.033).

Silica-free mineral content.--Philpot (1970) found the silica-free mineral content (S_e) of ponderosa pine and Douglas-fir bolewood to be equal to the total mineral content of these species; .002 and .001 fraction odw, respectively. The needles of ponderosa pine and white pine, however, have an S_e of .015 and .025, 10 times higher than the bolewood. Because the needle component contributes 78.6 percent of the surface area of the clearcut model and 72.8 percent of the partial cut model, the current NFDRS S_e value of .020 fraction odw appears appropriate for these two fuel types.

Ten- and 100-hour size class surface area-to-volume ratios.--The average values for ponderosa pine, lodgepole pine, Douglas-fir, and western hemlock σ_{10} and σ_{100} are given in table 6. The average σ_{10} of 3.06 cm^{-1} is 15 percent lower than the general parameter value of 3.58 cm^{-1}. This difference will have a negligible effect on the fire model's predictions. Similarly, the average σ_{100} from table 6 of 0.94 cm^{-1} is only a 4-percent decrease from the NFDRS value of 0.98 cm^{-1}, and would have almost no effect on the fire model's predictions. It appears, then, that the current general parameter values used by the NFDR System for σ_{10} and σ_{100} are representative of slash fuel species.

Moisture of extinction.--While the NFDRS considers the moisture of extinction (M_x) to be a general parameter, it appears in fact not to be a constant parameter attributable to a fuel type, but rather a variable dependent upon the fuel array properties. The M_x values that give good agreement between predicted and observed fire spread behavior on 16 experimental slash fires have been found to be positively correlated with the fuel array's characteristic load ($\tilde{\omega}_n$) ($r = .755$) and packing ratio (β) ($r = .480$), and inversely correlated with its characteristic surface area-to-volume ratio ($\tilde{\sigma}$)($r = -.876$). The M_x values ranged from 0.10 to .50 fraction odw. The relationship is expressed by the regression equation

$$M_x = 0.359+0.956\,\beta+0.021\,\tilde{\omega}_n-0.0049\,\tilde{\sigma}\ ; \quad (4)$$

where, M_x is the moisture of extinction value (fraction odw), β is the packing ratio (dimensionless), $\tilde{\omega}_n$ is the characteristic fuel load (kg/m^2), and $\tilde{\sigma}$ is the characteristic surface area-to-volume ratio (cm^{-1}). The equation has an R^2 of 0.80 and a standard error of estimate of 0.08. Equation 4 yields an M_x value of 0.182 for the clearcut model and 0.203 for the partial cut model. Use of the new M_x values would reduce spread predictions by 2 to 3 percent. Given the standard error of the regression at 0.08, we do not feel sufficient evidence exists to change the current M_x value of 0.25 fraction odw.

Fuel Model Performance

The performance of the clearcut and partial cut models were compared with that of the slash (I) model. The FIREMOD subroutines library was again employed using parameter values listed in table 10 as inputs for the three models.

Model performance was evaluated at four levels of fire danger. The low, moderate, high, and extreme fire dangers correspond to the 10, 50, 80 and 98th percentile worst fire weather days. The Plains, Montana AFFIRMS station was used to determine the percentile fuel moisture values. The station has 2,067 days of weather data between June 1 and September 1 over a 22-year period. The moisture contents (percents) at each danger level are given on the bottom of the next page.

Table 10--Suggested values for clearcut and partial cut slash fuel model parameters, as indicated by our analyses in comparison with the NFDRS Slash (I) Fuel Model[1/]

Fuel model	Fuel load (kg/m^2)			Fuel bed depth (cm)	σ_1 (cm^{-1})	M_x (fraction)
	1	10	100			
Clearcut	0.860	1.080	1.885	32.0	49.2	0.22
Partial cut	.410	.935	1.560	15.0	49.2	.24
Slash (I)	.897	1.121	2.242	106.7	49.2	.250

Fuel model	Packing ratio (dimensionless)	Optimum packing ratio	Optimum bed depth (cm)	Weighted average $\tilde{\sigma}$ (cm^{-1})	Weighted average $\tilde{\omega}_n$ (kg/m^2)
Clearcut	0.02330	0.00911	81.8	44.55	0.910
Partial cut	.03775	.00965	61.0	41.48	.532
Slash (I)	.00779	.00929	89.4	43.47	.948

Fuel model	h (j/g)	ρ_p (g/cm^3)	S_T (fraction)	S_e (fraction)	σ_{10} (cm^{-1})	σ_{100} (cm^{-1})
Clearcut	20 000	0.513	0.055	0.020	3.58	0.98
Partial cut	20 000	.513	.055	.020	3.58	.98
Slash (I)	18 603	.513	.055	.020	3.58	.98

[1/] σ_1 = 1-hour surface area/volume

M_x = moisture of extinction

$\tilde{\omega}_n$ = weighted average net fuel load

h = low heat of combustion

ρ_p = fuel particle density

S_T = total mineral content

S_e = silica-free mineral content

σ_{10} = 10-hour surface area/volume

σ_{100} = 100-hour surface area/volume

$\tilde{\sigma}$ = weighted average surface area/volume

(Tabulation from previous page.)

Danger level	Percentile	1-hour moisture	10-hour moisture	100-hour moisture
Low	10	13	18	16
Moderate	50	7	9	12
High	80	5	6	9
Extreme	98	3	2	6

Table 11 summarizes the predictions of fire spread for the three models under the influence of a 268.2-meter-per-minute (10.0-mile-per-hour) windspeed at midflame height and no terrain slope. While the three models produce distinctly different spread predictions, the clearcut and partial cut model values are much less than those of the slash (I) model. Clearcut model predictions are about one-fourth, and partial cut values one-sixteenth those of the slash (I) model's. This is primarily a result of the higher fuel array packing ratios for the former two models.

Discussion

The NFDRS is a danger rating system using normalized spread (SC) and energy release components (ERC) (Deeming et al. 1972). Each fuel model prediction is normalized against the highest spread rate of the flashiest fuel (grass) and the greatest intensity of the most intense fuel (chaparral). As noted by Rothermel,[3] such a normalization procedure greatly reduces the system's sensitivity to changes in fire danger in slow spreading or low intensity fuels. In the slash (I) model, for example, potential spread rate must increase by more than 2 meters per minute to increase the SC by one unit (see footnote 3). Since the partial cut and clearcut models produce spread rates significantly lower than the I model, their use would only decrease the sensitivity of the models.

Two solutions to the problem are possible. The first is to adjust each model so its spread and energy release values under extreme danger conditions approach those of the grass and chaparral models, respectively. The cause of the low spread rates in the clearcut and partial

Table 11--Rate of spread (ROS) performance of fuel models for various fire danger levels and as a ratio to rate of spread under extreme fire danger conditions

Model	Packing ratio	Low danger		Moderate danger		High danger		Extreme danger	
		ROS m/min	Low/extreme	ROS m/min	Moderate/extreme	ROS m/min	High/extreme	ROS m/min	Extreme/extreme
ash (I)	Net	14.20	0.499	19.42	0.682	22.53	0.791	28.47	1.00
earcut	Net[1/]	3.46	.498	4.73	.682	5.49	.791	6.94	1.00
	Adjusted[2/]	8.72	.497	11.93	.680	13.84	.790	17.50	1.00
	Weighted[3/]	21.19	.498	28.98	.681	33.64	.791	42.53	1.00
rtial ut	Net	.87	.488	1.21	.677	1.40	.785	1.79	1.00
	Adjusted	2.96	.488	4.11	.678	4.77	.785	6.07	1.00
	Weighted	9.36	.488	13.00	.678	15.05	.785	19.18	1.00

[1/] Net $\beta = (\omega_1 + \omega_{10} + \omega_{100})/\delta\rho_p$

[2/] Adjusted $\beta = (\omega_1 + \omega_{10})/\delta\rho_p$

[3/] Weighted $\beta = \tilde{\omega}_n/\delta\rho_p$

---

[3] Rothermel, R. C. 1974. Evaluating the National Fire Danger Rating System fire behavior indices. NFDRS Tech. Advis. Comm., meet. Nov. 13-14, 1974. Boise, Idaho. Northern For. Fire Lab., Drawer G, Missoula, Mont. 49 p.

cut models are their high packing ratios. As noted in the sensitivity analysis section, the fire model is quite sensitive to changes in this parameter.

The fire model was developed using uniform fuel beds of excelsior, 0.635-cm sticks, or 1.27-cm sticks. The determination of the fuel array packing ratio for such uniform beds is straightforward;

$$\beta = \omega/\delta\ \rho_p ; \qquad (5)$$

where, β is the packing ratio (dimensionless), ω is the fuel bed load, δ is the bed depth, and ρ_p is the fuel particle density. When applied to wildland fuels, the determination is not so straightforward. In such cases, the generally used and accepted formula is

$$\beta = \omega_n / \delta\ \rho_p ; \qquad (6)$$

where, ω_n is the 'net' fuel load, defined as the load of those fuels with a diameter less than 7.7 cm. This cut-off point is an artifact of the fuel sampling technique (Brown 1974) which divides dead and down fuels into 0- to .63-, .64- to 2.5-, 2.5- to 7.6-, and 7.7- + cm classes.

This presents the possibility of increasing the spread predictions of the clearcut and partial cut models by calculating the packing ratio using other cut-off points. It is important to note that the NFDRS is not concerned with actual spread rate predictions on a real-time basis but rather with relative fire danger rating. Table 11 contains clearcut and partial cut model spread predictions when the packing ratio is determined from only those fuels less than 2.54-cm diameter. The use of such 'adjusted packing ratio' values increases the two models' predictions closer to those of the slash (I) model. This does not alleviate the sensitivity problem, however, since the spread rates are still much less than the spread rate normalizing factor (210.6 m/min).

Another approach was to use the weighted 'characteristic' fuel load $\tilde{\omega}_n$ to determine the packing ratio. The weighted load is the load value used by the fire model to derive reaction intensity (Rothermel 1972) and spread rate. The contribution of each fuel size class load to the characteristic load is weighted by its surface area contribution to the array's total surface area. The use of the weighted characteristic fuel load increases the two models' predictions closer to that of the normalizing factor, making them more responsive to changes in fire danger. Interestingly, the clearcut model's predictions become about 50 percent higher and the partial cut model's predictions 33 percent lower than those of the slash fuel model.

It appears the use of the weighted characteristic fuel load in determining the packing ratio will increase the clearcut and partial cut models' sensitivity to changes in fire danger levels when the danger indices are normalized against high grass fuel spread rates. The two models will also yield danger values distinct from each other, with partial cut indices approximately half those of the clearcut model under similar danger conditions.

The second possible solution to the sensitivity problem suggested by Rothermel (see footnote 3) is to normalize the SC and ERC for each fuel model against its own maximum value under extreme danger conditions. This has the advantage of making the system equally responsive for each fuel model.

Should this approach be taken, the partial cut model should not be included in the 1977 version of the NFDRS. Table 11 demonstrates that if the low, moderate, and high danger spread rates are normalized against the extreme spread rate, all three models produce the same danger index at each level. For example, at low fire danger, the clearcut model spread is 0.498 that of its extreme spread rate. The partial cut model proportion is nearly identical at 0.488.

Conclusions and Summary

An evaluation of slash fuel load data indicates the existence of two statistically different fuel populations at the 1-percent level of significance. One population is associated with clearcut activities and the other with partial cut treatments. Both derived slash fuel populations are statistically different from the most similar non-slash fuel model currently used by the NFDRS, the Dense Conifer (G) model. If the level of significance were dropped to 5 percent, separate clearcut loads should be used for Pacific Northwest clearcuts and other clearcut slash.

The selected load values for the proposed clearcut model are very similar to that of the NFDRS slash (I) model for western conifer clearcuts. The partial cut model's total load is, however, only 68 percent that of the I model's (table 10), and thus represents the lower end of the load continuum. Both proposed fuel models have a much more compacted fuel bed than does the slash (I) model. The increase in packing ratio results in an approximately proportional decrease in the fire model's spread rate predictions. This will further decrease the NFDR System's sensitivity to changes in fire danger for the two new models.

To overcome this difficulty, two alternative recommendations are proposed. The first, as suggested by Rothermel (see footnote 3), is to normalize the SC and ERC against their respective maximum values for each individual fuel model rather than against the grass (A) and chaparral (B) models. This will make every model equally responsive to changes in fire danger relative to its inherent burning properties. Under this recommendation, the proposed partial cut model should not be included in the NFDRS as it will produce danger indices similar to those of the clearcut model.

The alternative recommendation is to increase fuel model spread rate predictions by using the weighted characteristic fuel load to determine the bed's packing ratio. With spread rates more nearly equal to the normalizing factor under extreme burning conditions, the indices of the two proposed models will be more responsive to changes in fire danger. Under this recommendation, both models should be included in the NFDRS as they will produce danger indices distinct from each other. The use of the weighted characteristic load in determining packing ratios for the two models has the same effect as increasing the clearcut model's depth from 32.0 to 134.6 cm, and the partial cut depth from 15.0 to 81.9 cm.

The fine fuels' surface area-to-volume ratio is a difficult parameter for which to derive a value since it must represent both needles and small branch wood. The range of values for this size class is therefore much greater than that of any other class. The influence of the more finely sized fuel particles on fire spread is a well known phenomenon. Because this parameter exerts a fair amount of control over the fire model's spread rate predictions, the creation of a separate fuel size class for particles with surface area-to-volume ratios of greater than 50.0 cm^{-1} (i.e., needles) merits consideration. In the absence of such a fourth size class, a σ_1 was chosen using appropriate weighting methods. The selected fine fuel surface area-to-volume ratio was found to be nonsignificantly different from the current NFDRS value of 49.2 cm^{-1}.

The only change recommended in the NFDRS general parameters is the inclusion of the low heat of combustion as a specific parameter in the newly proposed slash fuel models. Coniferous wood consistently has a low heat of combustion higher than the current value of 18 603 j/g, and this should be reflected in the parameter.

Literature Cited

Albini, F. A.
1976. Computer-based models of wildland fire behavior: a users' manual. USDA For. Serv. Intermt. For. and Range Exp. Stn. (unnumbered) 68 p.

Bevins, C. D.
1975. An evaluation of the slash fuel model of the 1972 National Fire Danger Rating System. M.S. thesis. Univ. of Washington, Seattle. 104 p.

Bevins, C. D.
1978. Fuel particle diameters of western hemlock slash. USDA Forest Service Res. Note INT-243. USDA Intermt. For. and Range Exp. Stn., Ogden, Utah. 3 p.

Brown, J. K.
1970a. Ratios of surface-area-to-volume for common fine fuels. For. Sci. 16:101-105.

Brown, J. K.
1970b. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res. Pap. INT-81. USDA For. Serv. Intermt. For. and Range Exp. Stn., Ogden, Utah. 9 p.

Brown, J. K.
1972. Handbook for inventorying downed woody material. USDA For. Serv. GTR-16. Intermt. For. and Range Exp. Stn., Ogden, Utah. 24 p.

Brown, J. K., and P. J. Roussopoulos.
1974. Eliminating biases in the planar intersect method of estimating volumes of small fuels. For. Sci. 20:350-356.

Corder, S. E.
1973. Wood and bark as fuel. For. Res. Lab., Res. Bull. No. 14. Oregon State Univ., Corvallis. 28 p.

Deeming, J. E., and J. W. Lancaster.
1971. Background, philosophy, and implementation--National Fire Danger Rating System. USDA For. Serv. Fire Control Notes 32(2):4-8.

Deeming, J. E., J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder.
1972. National Fire Danger Ratin System. USDA For. Serv. Res. Pap. RM-84. 53 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. (Revised August 1974).

Fahnestock, G. K.
1960. Logging slash flammability USDA For. Serv. Res. Pap. No. 5 67 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Frandsen, W. H.
1974. A fire spread model for spatially nonuniform forest floor fuel arrays. Paper presented to Western States Sec. The Combustion Institute, Northbridge, Calif., Oct. 21-22, 1974. 33p.

Mission Research Corp.
1975. Rate of spread model sensitivity analysis. Volume V, A simulation for Wildland Fire Management Planning Support. MRC Rep. 7512-6-1075. 40 p. Santa Barbara, Calif.

Philpot, C. W.
1970. Influence of mineral content in the pyrolysis of plant material. For. Sci. 16:451-471.

Rothermel, R. C.
1972. A mathematical model for predicting fire spread in wildland fuels. 40 p. USDA For. Serv. Res. Pap. INT-115. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Schroeder, M. J., M. A. Fosberg, J. W. Lancaster, J. E. Deeming, and R. W. Furman.
1972. Technical development of the National Fire Danger Rating System. Tech. Bull. Natl. Fire Danger Rating Syst. Work Unit, Missoula, Mont.

Schmidt, R. G.
1975. A hazard appraisal system for southwest Oregon. M.S. thes Coll. of For. Resour., Univ. of Washington, Seattle. 149 p.

Sneeuwjagt, R. J.
1974. An evaluation of the grass fuel model of the National Fire Danger Rating System. M.S. thesis, Univ. of Washington, Seattle. 162 p.

Swanson, J. R.
1974. Prescribed underburning for wildfire hazard abatement in second-growth stands of west-side Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). M.S. thesis, Coll. of For. Resour., Univ. of Washington, Seattle. 130 p.

Bevins, Collin D., and Robert E. Martin.
1978. An evaluation of the slash (I) fuel model of the 1972 National Fire Danger Rating System. USDA For. Serv. Res. Pap. PNW-247, 17 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The slash (I) fuel model of the 1972 National Fire Danger Rating System was evaluated for homogeneity within the model and for differences from other fuel models. Clearcut slash is different from partial cut slash at the 1-percent level of confidence. Pacific Northwest clearcut slash loads are different from other clearcut slash at the 5-percent level. New fuel models are proposed.

KEYWORDS: Fire danger rating, slash, fire behavior (Forest), fuels (forest fire), models.

Bevins, Collin D., and Robert E. Martin.
1978. An evaluation of the slash (I) fuel model of the 1972 National Fire Danger Rating System. USDA For. Serv. Res. Pap. PNW-247, 17 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The slash (I) fuel model of the 1972 National Fire Danger Rating System was evaluated for homogeneity within the model and for differences from other fuel models. Clearcut slash is different from partial cut slash at the 1-percent level of confidence. Pacific Northwest clearcut slash loads are different from other clearcut slash at the 5-percent level. New fuel models are proposed.

KEYWORDS: Fire danger rating, slash, fire behavior (Forest), fuels (forest fire), models.

Bevins, Collin D., and Robert E. Martin.
1978. An evaluation of the slash (I) fuel model of the 1972 National Fire Danger Rating System. USDA For. Serv. Res. Pap. PNW-247, 17 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The slash (I) fuel model of the 1972 National Fire Danger Rating System was evaluated for homogeneity within the model and for differences from other fuel models. Clearcut slash is different from partial cut slash at the 1-percent level of confidence. Pacific Northwest clearcut slash loads are different from other clearcut clash at the 5-percent level. New fuel models are proposed.

KEYWORDS: Fire danger rating, slash, fire behavior (Forest), fuels (forest fire), models.

Bevins, Collin D., and Robert E. Martin.
1978. An evaluation of the slash (I) fuel model of the 1972 National Fire Danger Rating System. USDA For. Serv. Res. Pap. PNW-247, 17 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The slash (I) fuel model of the 1972 National Fire Danger Rating System was evaluated for homogeneity within the model and for differences from other fuel models. Clearcut slash is different from partial cut slash at the 1-percent level of confidence. Pacific Northwest clearcut slash loads are different from other clearcut slash at the 5-percent level. New fuel models are proposed.

KEYWORDS: Fire danger rating, slash, fire behavior (Forest), fuels (forest fire), models.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

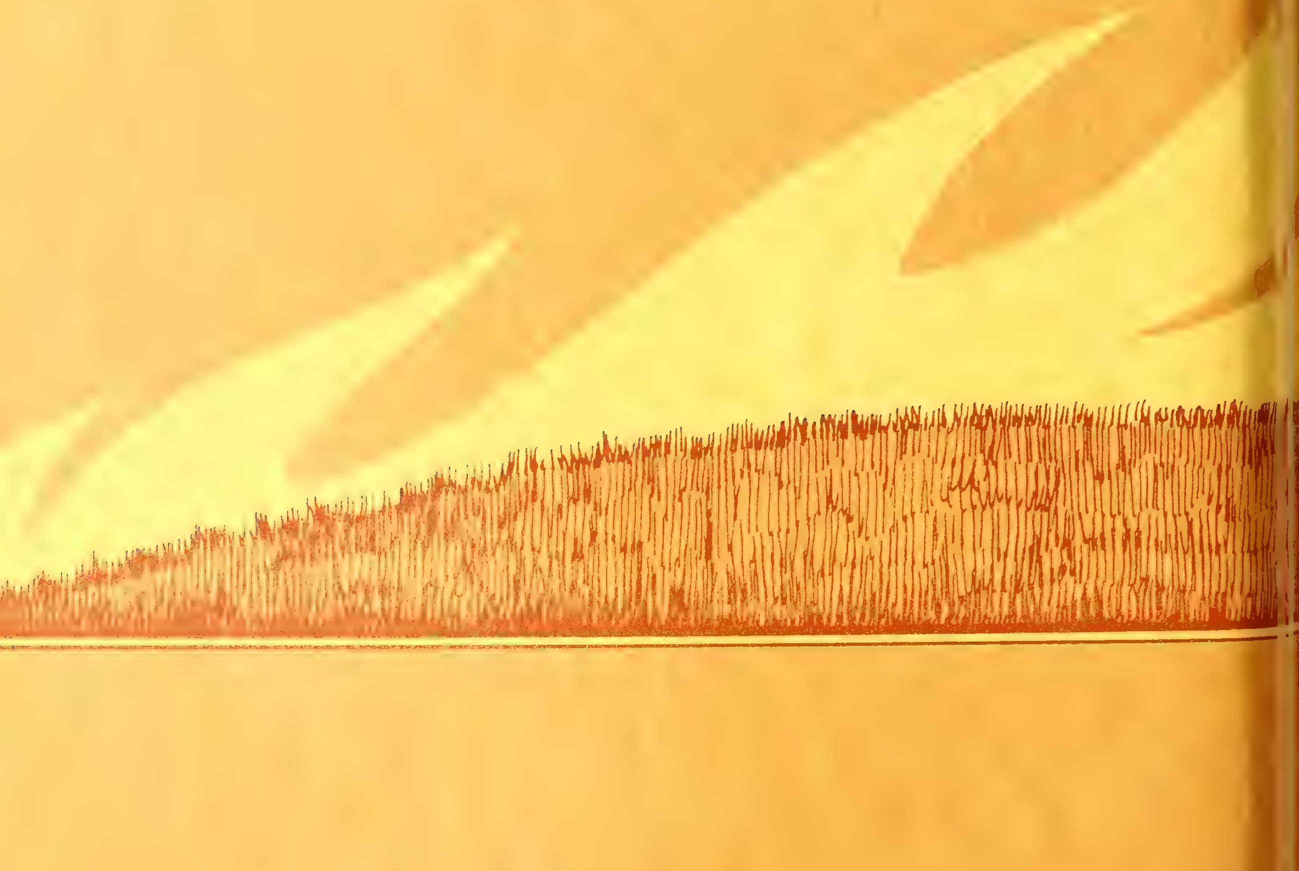
The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives – as directed by Congress – to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.



Research Paper PNW-248

1979

CLEMSON UNIVERSITY LIBRARY
MAR 29 1979
SCI., TECH. & AGR. DIV.

GOVT. DOCUMENTS
DEPOSITORY ITEM

CLEMSON
LIBRARY

Regeneration in MIXED CONIFER CLEARCUTS in the Cascade Range and the Blue Mountains of Eastern Oregon

K.W. SEIDEL

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

* *

Metric Conversion

1 foot = 0.3048 m
1 inch = 2.54 cm
1 acre = 0.4047 ha
1 tree per acre = 2.47 trees per hectare

* *

REGENERATION IN MIXED CONIFER CLEARCUTS IN THE CASCADE RANGE AND BLUE MOUNTAINS OF EASTERN OREGON

Reference Abstract

Seidel, K. W.
1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of clearcuts in mixed conifer forests of the Cascade Range and Blue Mountains of eastern Oregon showed that, on the average, clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. Planted ponderosa pine dominated clearcuts at elevations of less than 5,300 feet; and at higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present. Seedling establishment was better on more northerly aspects while increasing amounts of grass had a negative effect on stocking.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), Oregon (Blue Mountains), silvicultural systems (clearcutting).

RESEARCH SUMMARY

Research Paper PNW-248

1979

A regeneration survey of clearcuts in mixed conifer forest in the Cascade Range and Blue Mountains of eastern Oregon was made to obtain an overview of reforestation status and to identify key environmental factors influencing regeneration establishment. Plots were randomly located in clearcuts harvested during the 1953-1973 period in the mountain hemlock/grouse huckleberry and mixed conifer/snowbrush-chinkapin communities in the Cascades and in the grand fir/big huckleberry community in the Blue Mountains.

On the average, clearcuts were well stocked with a mixture of advance, natural, and planted reproduction of a number of species. At elevations below 5,300 feet, planted ponderosa pine was the dominant species because of its good survival and fast growth. Considerable amounts of vigorous true fir and mountain hemlock advance reproduction were present in some of the higher elevation Cascade plots. Natural regeneration was generally present in adequate numbers, but distribution was sometimes patchy, and it was often in a subordinate position beneath trees or woody vegetation.

Greater stocking was generally associated with more northerly aspects and less stocking with increasing amounts of grass. Other factors such as age, slope, and forbs had a positive or negative effect on stocking depending upon the species and community.

Planting ponderosa pine in clearcuts below 5,300 feet where vigorous advance reproduction is lacking has resulted in fast growing, well stocked stands and is the preferred reforestation method. At higher elevations, lodgepole pine is a desirable species to plant because of its greater resistance to snow damage. Planting stock should be used that was grown from seed collected in the same geographical and elevational zone as the clearcut. If sufficient numbers of vigorous advance reproduction exist to form the new stand, careful logging and slash disposal methods to save these trees will eliminate the problems associated with natural or artificial regeneration. Natural regeneration after clearcutting is an uncertain reforestation method because so many factors involved are beyond the forester's control. It is, therefore, most useful as a means of supplementing existing advance or planted reproduction.

Contents

INTRODUCTION 1

OBJECTIVES 1

STUDY AREAS 1
  Eastern Cascades 1
  Blue Mountains 2

METHODS 3
  Survey Design and Plot Selection 3
  Data Collection 4
  Data Analysis 4

RESULTS AND DISCUSSION 5
  Eastern Cascades 5
    Regeneration Stocking and Density 5
    Species Composition of Regeneration 8
    Dominant Species 9
    Relation of Present Stocking to Environmental Factors 11
    Prediction Equations 13
  Blue Mountains 13
    Regeneration Stocking and Density 13
    Species Composition of Regeneration 17
    Dominant Species 17
    Relation of Present Stocking to Environmental Factors 18
    Prediction Equations 20

CONCLUSIONS AND RECOMMENDATIONS 20

LITERATURE CITED 22

APPENDIX 24

Introduction

Mixed conifer forests on the east side of the Oregon Cascade Range and in the Blue Mountains of northeastern Oregon contain a variety of species growing in diverse environments. During the 1950's and early 1960's, clearcutting was the primary method of harvesting timber in these forests. More recently, the shelterwood system has been used to increase the probability of obtaining natural regeneration by moderating harsh microclimates found on many high elevation sites or improving the esthetic quality of harvest cuttings.

Success of regeneration on these clearcuts has been mixed, ranging from poor to good in various locations, but there has been no broad-scale attempt to evaluate the regeneration or to relate it to environmental factors. Clearcuts in eastern Oregon mixed conifer forests are now old enough for regeneration to be established. Therefore, in 1976, I began a survey of regeneration on these clearcuts and a study of the factors affecting its establishment. This paper reports the results of the field survey conducted during 1976 and 1977 on the Deschutes, Winema, Umatilla, and Wallowa-Whitman National Forests.

Objectives

The purpose of this study was twofold: (1) to quantify regeneration found on the clearcuts and (2) to identify environmental factors associated with the presence or absence of regeneration.

Specific study objectives were:

1. To determine success of regeneration in terms of stocking percentage and density (number per acre);

2. To determine species composition of regeneration;

3. To determine origin of regeneration as preharvest (advance) or postharvest (natural and planted); and

4. To determine the relationship between regeneration and some measurable environmental factors such as elevation, aspect, slope, and time since harvest.

Study Areas

Stand structure and species composition of mixed conifer forests in eastern Oregon are extremely variable, depending upon site, logging history, insect and disease attacks, and wildfire. Within the broad, general area classified as mixed conifer forests, a number of forest zones are recognized based on the single species which is the major climax dominant. These forest zones are described by Franklin and Dyrness (1973). Major tree species found in these zones are ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Dougl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.), Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), western white pine (*Pinus monticola* Dougl.), western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.).

EASTERN CASCADES

A number of plant communities have been identified within mixed conifer forests on the east side of the Oregon Cascades by Volland (1976). Identification was based on the dominant overstory tree along with the dominant understory shrub, forb, or grass. Study areas (plots) were located in two of these plant communities: (1) a high elevation mountain hemlock/grouse huckleberry community and (2) a lower elevation mixed conifer/snowbrush-chinkapin community (table 1). Understory vegetation in the mountain hemlock/grouse huckleberry community is generally sparse, consisting primarily of grouse huckleberry (*Vaccinium scoparium*), Prince's pine (*Chimaphila umbellata*), and pinemat manzanita (*Arctostaphylos nevadensis*). Major

Table 1--Mean and range of some characteristics of clearcut areas sampled in Cascade and Blue Mountain plant communities of eastern Oregon

Characteristic	Cascades				Blue Mountains	
	Mt. hemlock/ grouse huckleberry		Mixed conifer/ snowbrush-chinkapin		Grand fir/big huckleberry	
	Mean	Range	Mean	Range	Mean	Range
No. of plots	28	--	15	--	50	--
Clearcut size (acres)	29	10-80	24	10-50	31	10-120
Elevation (feet)	5,980	5,200-6,800	4,780	4,100-5,900	4,737	3,800-6,300
Slope (percent)	11.8	0-40	7.1	0-22	9.7	0-40
Age (years)	14.3	3-19	12.9	4-16	16.3	10-22
			Seedbed (percent coverage)[1]			
Mineral soil	25.5	2-60	27.3	5-75	10.3	0-40
Litter	19.9	5-40	31.5	2-50	45.9	13-75
Slash	22.1	11-45	16.1	6-26	18.5	10-30
Litter & slash	20.8	3-45	21.4	2-43	19.3	5-40
			Understory vegetation (percent coverage)			
Forbs	1.1	0-20	2.5	0-13	41.5	0-66
Woody	17.4	0-58	18.8	0-40	22.5	0-62
Grass & sedge	11.5	0-35	17.4	0-50	22.2	0-56

[1] Total of all seed bed categories do not add to 100 percent because of small areas of some quadrats occupied by rocks and stumps.

understory vegetation in the mixed conifer/snowbrush-chinkapin community consists of snowbrush (*Ceanothus velutinus*), golden chinkapin (*Castanopsis chrysophylla*), pinemat manzanita, dogbane (*Apocynum pumilum*), and fireweed (*Epilobium angustifolium*).

Study areas are within the pumice plateau region of south-central Oregon (fig. 1). Soils in this region are immature Regosols (Vitrandepts) developed from aerially deposited dacite and rhyolitic pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. These well-drained, coarse-textured soils have thin A horizons low in fertility which grade into unweathered sand and gravel. A finer textured buried soil is found at a depth of 2 to 6 feet (Larsen 1976).

BLUE MOUNTAINS

Plant communities of the Blue Mountains of eastern Oregon have been described by Hall (1973). All of the clearcuts examined in this study were located in the grand fir/big huckleberry community in the Umatilla and Wallowa-Whitman National Forests (fig. 1). Understory vegetation in mixed conifer forests of the Blue Mountains is much more diverse than in the Cascade Range, especially the forb component which averaged 41.5-percent cover compared to only 1.1 percent in the Cascade mountain hemlock forest (table 1). Principal understory species are big huckleberry (*Vaccinium membranaceu* heartleaf arnica (*Arnica cordifolia*), sideflower mitrewort (*Mitella stauropetala*), piper anemone (*Anemone piperi*), yarrow (*Achillea millefolium* strawberry (*Fragaria virginiana*), prickly currant (*Ribes lacustre*),

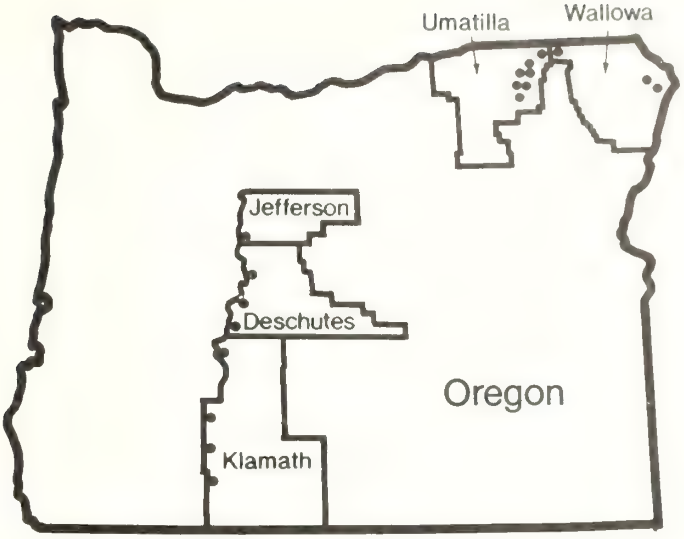


Figure 1.--Study area locations in Oregon. Four to seven plots were sampled in the vicinity of each dot.

baldhip rose (*Rosa gymnocarpa*), and dwarf blackberry (*Rubus lasiococcus*).

Predominant soils of the grand fir/big huckleberry community are the Regosols (Vitrandepts) developed in the ash layer deposited from Mount Mazama or Glacier Peak. These are well-drained soils with silt loam A-C horizons over older buried soils or basalt (Wade 1975).

Methods

SURVEY DESIGN AND PLOT SELECTION

Clearcut areas within the east-side Oregon Cascades and the Blue Mountain region were considered as separate populations. A record of areas clearcut between 1953 and 1973 in the mixed conifer forest was obtained from the U.S. Forest Service Regional Office in Portland, Oregon. In this study, the sampling unit was a square plot 10 acres in size. Therefore, all clearcuts 10 acres or larger were considered as candidate areas for sampling. The total number of 10-acre units in the clearcuts in each geographic region was then determined (fractional portions of 10-acre areas were not included).

In each geographic region 50 samples (plots) were then selected at random from the total number in that region. In most cases, this resulted in only one sample per clearcut; but several of the larger clearcuts were sampled with two or more plots. Within each clearcut, sample plot or plots were located in the same manner as sections are numbered in a township, beginning at the northeast part of the clearcut.

Candidate sample plots were rejected if they contained three or more living seed trees per acre, if the area was seeded with tree species, or if it had been converted to nonforest uses. When a plot was rejected, it was replaced by another from a random list of alternate plots. Because of time limitations, only 43 plots were sampled in the Cascade Range.

Some clearcuts were stocked with varying amounts of advance reproduction.

It is more accurate to refer to the harvesting method in these units as an overstory removal or the final cut in a shelterwood system rather than a clearcut. For the purpose of this study, however, units were considered clearcuts if all of the mature overstory was cut.

DATA COLLECTION

A grid of 25 sample point locations (subplots) was centrally located on each 10-acre plot. Circular subplots were systematically spaced at 1-chain intervals on five parallel lines 1 chain apart containing five subplots each. At each of 25 sample point locations in the plot, two concentric subplots (1- and 4-milacre) were examined for regeneration and associated environmental variables. Individual sample points were rejected if conditions such as streambeds, marshs, swamps, active roads, gravel, cinder pits, solid rock, or erosion occurred on more than one-half of the subplot thus making it unsuitable for regeneration. (Only 0.3 percent of the subplots were rejected for these reasons.)

Information about the clearcut unit and the timber stand in which it was located was obtained from Ranger District records and from field observations. Information obtained was the plant community in which the plot was located, average elevation, timber type, date of harvest, slash treatment method and year of treatment, species planted and year of planting, subsequent cultural treatments, and general notes on regeneration size, growth, distribution, or damage. The plant community was identified by observing adjacent uncut stands.

On each 1-milacre subplot the total number of trees of each species was counted and recorded by class (origin). Regeneration was classified as being of preharvest (advance) origin or of postharvest (subsequent) origin. Trees of subsequent origin were further subdivided into 1- and 2-year-old seedlings from natural seedfall, seedlings 3 years and older from natural seedfall, and planted trees. On each 4-milacre subplot, the species and origin (advance, natural subsequent, or planted) of the tree most likely to dominate the subplot because of its size and vigor was recorded.

Identification of planted trees was accomplished by using information on species planted, date of planting, and spacing. In clearcuts where plantation survival was high, regular rows of planted trees were clearly visible. Planted tree identification was less certain when survival was low, but counting whorls to check tree age helped to determine the planted trees.

On each 1-milacre subplot, the following environmental factors were observed and recorded:[1] aspect, slope, seed bed condition (mineral soil, litter, slash), degree of burn, understory vegetation (forbs, woody, grass), distance from subplot to timber edge, and presence or absence of animal damage.

DATA ANALYSIS

To illustrate the present degree of reforestation, data were summarized in a number of tables showing tree numbers and stocking percentage by species and origin for the plant communities. To determine the relationship between regeneration and environmental variables, stepwise multiple regression procedures were used to fit linear equations of the form $Y = b_0 + b_1X_1 + b_2X_2 + \ldots b_nX_n$ to the data. Dependent (Y) variables used were stocking percentage of the various species and origins, and independent (X) variables were the environmental factors given in the appendix.

---

[1] See appendix for details of procedures for measuring and coding the environmental factors.

Results and Discussion

EASTERN CASCADES

Regeneration Stocking and Density

Regeneration on clearcuts in both the mountain hemlock/grouse huckleberry and the mixed conifer/snowbrush-chinkapin communities was adequate in terms of all species established before and after logging. An average of 53 percent of the milacre subplots were stocked in 28 plots in hemlock type compared with 59 percent in mixed conifer community (table 2). If total stocking is evaluated on the basis of 4-milacre quadrats, 80 percent of the subplots were stocked in the hemlock clearcuts and 92 percent in the mixed conifer.

Relative importance of advance reproduction and planted stock in the two plant communities can be seen in table 2. In the hemlock clearcuts, advance reproduction was the second largest component of the regeneration (509 stems per acre), while in the mixed conifer clearcuts, it was smallest (43 stems per acre). On the other hand, planted trees were a major component of regeneration in mixed conifer clearcuts, but only a minor part of the total in hemlock type. The differences in abundance of advance reproduction can be explained by the lack of slash treatment on 14 of the plots in the hemlock type.

Table 2--Average stocking percentage and number per acre, with standard errors, of all species on clearcuts in the east-side Oregon Cascades, by class of reproduction and plant community (based on 1-milacre quadrats)

Class of reproduction	Plant community					
	Mt. hemlock/grouse huckleberry			Mixed conifer/snowbrush-chinkapin		
	No. plots	Mean ± S.E.	Range	No. plots	Mean ± S.E.	Range
			Stocking percent			
Advance	28	18.2±4.1	0-72	15	3.1±1.3	0-16
Subsequent						
1 & 2 years	28	16.9±3.9	0-72	15	23.2±4.7	4-64
3 years and older	28	27.4±4.4	0-72	15	19.7±4.0	0-68
Planted	18	14.0±2.8	0-40	14	37.4±3.6	16-60
All classes except 1 & 2 years	28	45.4±4.1	4-96	15	48.3±3.6	28-72
All classes	28	53.0±4.9	4-96	15	58.7±3.1	36-80
			Number per acre			
Advance	28	509±147	0-3200	15	43±18.1	0-200
Subsequent						
1 & 2 years	28	386±133	0-3160	15	491±141	80-2000
3 years and older	28	593±119	0-2080	15	333±71	0-840
Planted	18	149±29	0-400	14	431±45	160-720
All classes except 1 & 2 years	28	1203±229	40-5120	15	779±93	280-1200
All classes	28	1589±263	80-5440	15	1269±156	480-2640

Because slash was undisturbed, more advance reproduction remained in these clearcuts than in the mixed conifer clearcuts where all the slash was treated (generally piled and burned). The poorer stocking of planted trees on the mountain hemlock clearcuts can be attributed in part to reduced survival of planted ponderosa pine at the higher elevations.

A considerable number of 1- and 2-year-old seedlings were present on clearcuts in both plant communities. In fact, this class of reproduction comprised the single largest category (491 per acre) in the mixed conifer clearcuts (table 2). The role of these seedlings in the total regeneration picture, however, is not as great as their numbers might suggest. Many of these young seedlings will die. And, it was noted that most of these seedlings were found growing in suppressed positions under woody vegetation or beneath larger planted or advance reproduction. The primary effect of these young seedlings was to increase the density of the regeneration rather than to greatly raise stocking levels. In the mountain hemlock clearcuts, for example, stocking was increased on 50 percent of the plots, but on only 3 of the 28 plots was the gain more than 12 percent. In the mixed conifer clearcuts, stocking was raised on 80 percent of the plots, but on only 4 of 15 was the gain more than 12 percent.

As expected, a highly significant exponential relationship was found between total number of trees per acre and percentage of stocked milacres (fig. 2). This is the same general type of relationship reported in other studies of natural regeneraton (Bever 1949, Harris 1967, Lynch and Schumacher 1941, Wellner 1940). This relationship shows that there are always more trees per acre than the number indicated by the minimum level curve which shows the theoretical

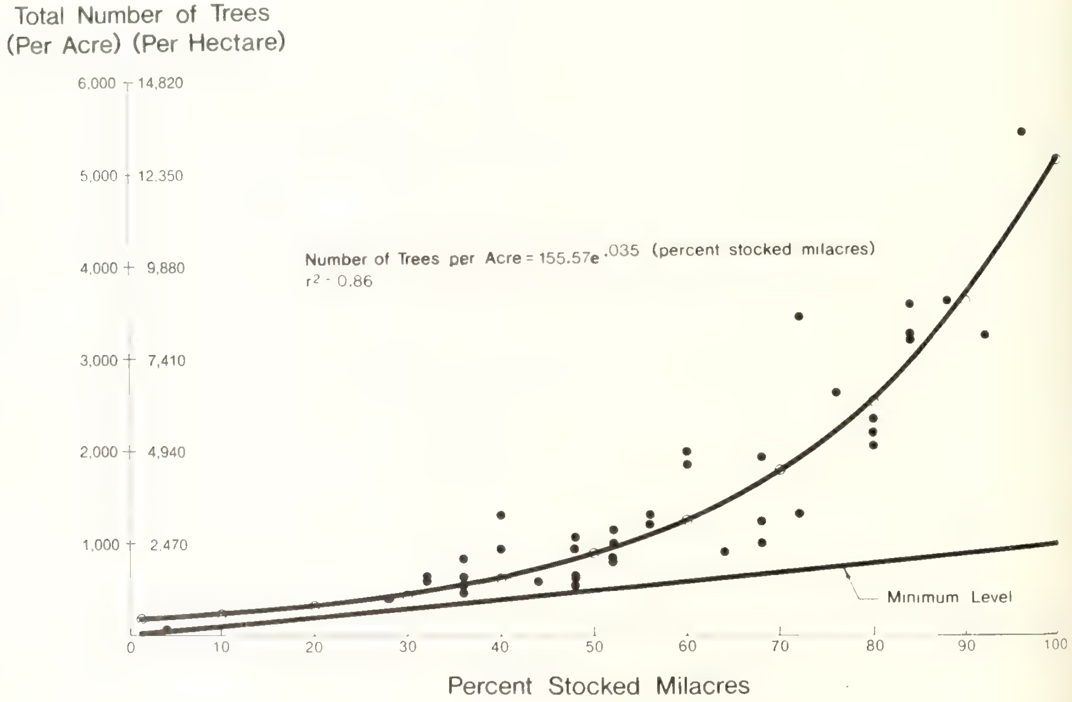


Figure 2.--Relationship of 1-milacre-stocking percent to total number of trees per acre for all 43 plots in the eastern Cascades. The minimum level curve indicates the expected relationship if there were no more than one tree per stocked milacre.

lationship if there were only one ee on each stocked milacre.

In addition to average stocking density of reproduction, plots re grouped into several stocking asses to provide insight into the generation status on the clearcuts. r this purpose, plots in both ant communities were grouped ac-rding to the number and percentage ich attained specific levels of ocking or density (table 3). pending on one's definition of equate stocking, the proportion clearcut areas successfully generated can be determined. For ample, if 40-percent stocking of lacre quadrats is considered tisfactory, then 50 percent of e clearcuts in mountain hemlock et this standard compared with percent of clearcuts in mixed nifer.

While surveying plots in mountain mlock community, it was obvious at the 10 plots that had not been nted had much more reproduction an 18 plots that had been planted.

Summarizing the data for planted and unplanted plots revealed that not only was there about five times as much advance reproduction on the unplanted plots as on the planted plots but numbers and stocking of 3-year and older subsequent reproduction were also much greater on the unplanted plots (table 4). The reason for these sizeable differences in stocking became apparent after looking at the same plots in terms of slash versus no slash treatment which corresponded closely to the planted versus unplanted grouping except for four plots that had been planted but where slash was left untreated. Much more advance reproduction was found on the unplanted plots because it was not destroyed during slash disposal. The reason for better stocking of subsequent regeneration on the untreated plots is not as apparent but may be due, in part, to the beneficial effects of the slash in modifying the microclimate at the soil surface.

Table 3--Proportion of clearcut plots in east-side Oregon Cascades stocked at various levels with 3-year and older regeneration (advance and subsequent)[1]

Stocking percent			Number trees/acre		
Minimum stocking	Samples	Proportion of total	Minimum stocking	Samples	Proportion of total
Percent	Number		No./acre	Number	
		Mt. hemlock/grouse huckleberry--28 plots			
20	24	0.86	200	26	0.93
40	14	.50	400	20	.71
60	9	.32	700	14	.50
80	5	.18	1000	11	.39
			2000	5	.18
		Mixed conifer/snowbrush-chinkapin--15 plots			
20	15	1.00	200	15	1.00
40	11	.73	400	13	.87
60	4	.27	700	8	.53
80	0	.00	1000	4	.27
			2000	0	.00

[1] Based on 1-milacre quadrats.

Table 4--Average stocking percentage and number per acre, with standard errors, of planted, unplanted slash treated, and untreated clearcuts in the Cascade mountain hemlock/grouse huckleberry community by class of reproduction (based on 1-milacre subplots)

Class of reproduction	Planted		Unplanted		Slash treated		Slash not treated	
	Stocking percent	Number per acre	Stocking percent	Number per acre	Stocking percent	Number per acre	Stocking percent	Number per acre
Advance	9.1±2.9	224±81	34.4±8.3	1020±337	6.9±2.6	157±73	32.9±5.3	860±256
Subsequent 3 years and older	18.2±3.2	353±91	44.0±8.9	1024±243	18.0±3.9	349±112	36.9±7.2	837±193
Planted	14.0±2.8	149±29	--	--	14.3±3.5	125±22	13.3±5.1	77±11
All classes except 1st and 2d years	36.4±4.5	726±148	61.6±10.2	2044±488	33.4±5.7	631±172	57.4±7.3	1774±371

Advance reproduction played an important regeneration role on the mountain hemlock clearcuts not only because of amounts present but also because of its size and growth potential. No systematic height growth measurements were taken in this study, but occasional observations of annual height growth of 1 to 2 feet were not uncommon on vigorous full-crowned true firs and hemlocks. Of course, not all advance reproduction is sufficiently vigorous to respond to release quickly; but if adequate numbers of healthy trees remain after logging, uncertainties of establishing a new stand by planting or natural regeneration can be avoided.

Species Composition of Regeneration

The regeneration in both plant communities was composed of a mixture of species. In the mountain hemlock type, more subplots were stocked with Shasta red fir (advance and subsequent) than any other species (table 5). Mountain hemlock was also a major species; stocking of advance and subsequent regeneration was about equal. The other two major species were white pine and lodgepole pine, primarily of older subsequent origin. If all origins are combined, average stocking of the four major species is ranked as follows: Shasta red fir, 25.4 percent; lodgepole pine, 17.3 percent; mountain hemlock, 13.9 percent; western white pine, 9.1 percent. Most of the reproduction on these clearcuts was of natural origin. Lodgepole pine was the primary species planted and accounted for 64 percent of the lodgepole pine regeneration on the nine plots where it was planted but for only 17 percent of the total number of trees on these plots. Some plots were also planted with true firs and western white pine, but they contributed little to the total stocking.

Species composition in the mixed conifer/snowbrush-chinkapin community differed considerably from the mountain hemlock. Grand fir and ponderosa pine were the two major species present--on the average occurring on 25.3 and 33.6 percent of the subplots, respectively (table 5). Lodgepole pine was the third most common species on the mixed conifer clearcuts and minor amounts of Shasta red fir, Douglas-fir, and western white pine were also found. Grand fir stocking of young and older postharvest origin was about equal while 94 percent of the ponderosa pine stocking originated from planting.

During the survey, I observed that ponderosa pine was planted not only on clearcuts in the mixed conifer forest but also on some of

Table 5--Average stocking percentage, with standard errors, of advance and subsequent regeneration on clearcuts in the east-side Oregon Cascades by species and plant community (based on 1-milacre subplots)

Species	Mt. hemlock/grouse huckleberry				Mixed conifer/snowbrush chinkapin			
	Advance	Subsequent[1]		All classes	Advance	Subsequent[1]		All classes
		3 years and older	1 and 2 years old			3 years and older	1 and 2 years old	
	Stocking percent (± standard error)							
Grand fir	0.7±0.4	1.3±0.6	0.6±0.3	1.6±0.6	1.9±0.8	12.0±3.3	16.3±3.3	25.3±4.1
Shasta red fir	9.7±3.2	13.0±2.7	8.1±2.9	25.4±4.9	3.1±1.4	2.1±1.2	2.1±0.9	5.6±2.1
Pacific silver fir	0.1±0.1	1.0±0.6	3.4±2.6	4.4±2.7	0.0± --	0.0± --	0.0± --	0.0± --
Douglas-fir	0.0± --	0.3±0.2	0.3±0.3	0.4±0.3	0.3±0.3	2.9±1.7	1.3±0.6	4.0±1.8
Mountain hemlock	6.6±1.6	6.0±1.4	2.1±0.8	13.9±2.5	0.0± --	0.0± --	0.0± --	0.0± --
Engelmann spruce	0.1±0.1	0.1±0.1	0.0± --	0.3±0.3	0.0± --	0.8±0.6	0.5±0.4	1.1±0.8
Western white pine	2.6±0.9	6.1±1.9	0.7±0.3	9.1±2.3	0.3±0.3	2.4±0.9	1.5±0.9	3.5±1.3
Ponderosa pine	0.3±0.3	4.1±1.8	0.0± --	3.4±1.7	0.0± --	31.2±5.5	0.3±0.3	33.6±5.0
Lodgepole pine	3.6±1.5	12.7±2.6	3.7±1.4	17.3±3.2	0.0± --	4.8±2.4	6.4±3.9	9.3±4.9

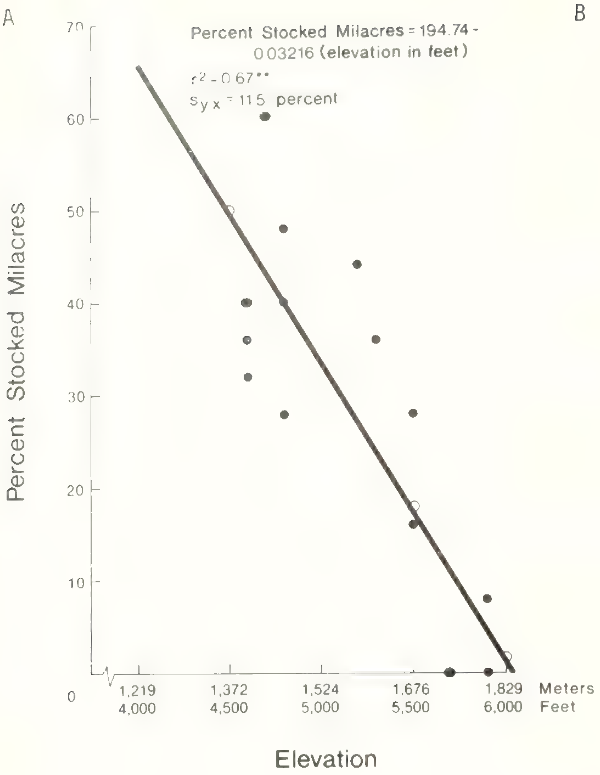
[1] Includes natural and planted regeneration.

the higher elevation clearcuts in the mountain hemlock. There appeared to be a noticeable decrease in ponderosa stocking with increasing elevation although all plots had been planted at an 8- x 8-foot spacing (681 trees per acre). Analysis of the data showed there was a highly significant negative linear relationship between planted ponderosa pine stocking percent or number of trees and elevation (fig. 3). In addition to the increase in mortality associated with greater elevation, there was also a noticeable increase in the amount of snow damage (stem deformation and breakage).

Dominant Species

Measurements of stocking and density alone do not give a complete picture of the regeneration pattern. A species may predominate in terms of numbers and yet be less important in the immediate future of the developing stand than another species that is less abundant but larger or more vigorous. This situation occurred in this study. In the mountain hemlock clearcuts, planted lodgepole pine was a minor regeneration component in terms of numbers but was classified as the dominant tree on 18.7 percent of stocked subplots--the largest percentage of any species-origin combination (table 6). It is obvious that reproduction on the mountain hemlock clearcuts is composed of a number of dominant species (Shasta red fir, mountain hemlock, white pine, and lodgepole pine) and is about equally divided among advance, natural subsequent, and planted origin.

In contrast to the mixed species and origin classes of reproduction in the mountain hemlock clearcuts, regeneration in the mixed conifer clearcuts is dominated by one species-planted ponderosa pine. Planted trees were dominant on 82 percent of the stocked subplots; ponderosa pine on 76 percent and Douglas-fir on 6 percent (table 6). True fir regeneration was dominant on only 10 percent of the stocked subplots even though present in considerably greater numbers than the planted ponderosa pine. Prompt reforestation of these clearcuts with planted ponderosa pine is clearly superior to waiting for natural regeneration to do the job. Many of the planted pine are now 3- to 5-inch d.b.h., 10 to 15 feet tall, and growing 1 to 2 feet annually in height. On the other hand, most of the natural fir regeneration was less than 4 feet tall and growing in the shade of the pines.



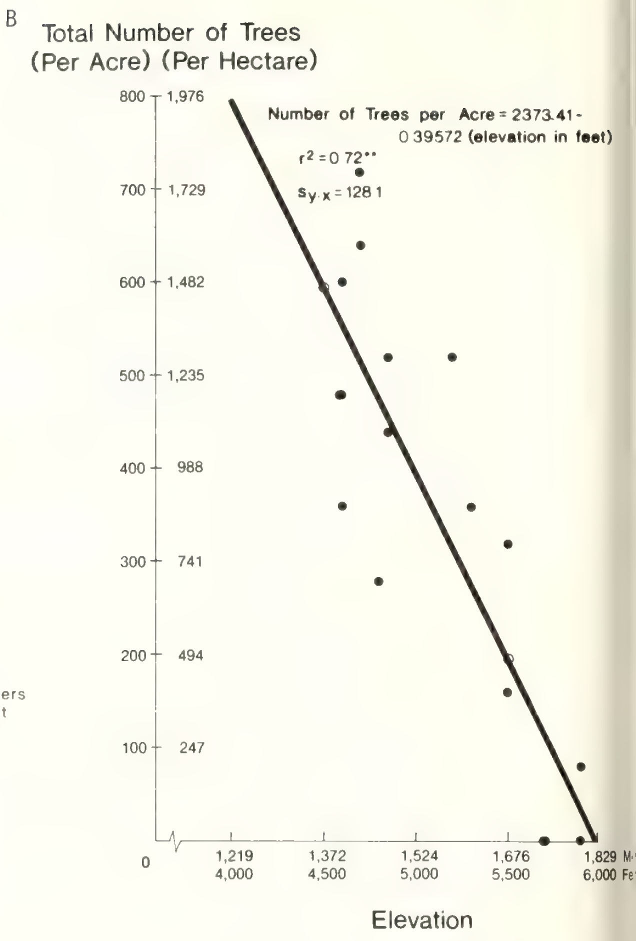


Figure 3.--In the eastern Cascades, establishment of planted ponderosa pine decreased as elevation increased: A--In stocked milacres; B--in number of trees per acre.

Table 6--Species and origin of dominant trees on east-side Oregon Cascade clearcuts by plant community[1/]

Origin	Species								
	Grand fir	Shasta red fir	Pacific silver fir	Douglas-fir	Mt. hemlock	Western white pine	Ponderosa pine	Lodgepole pine	Total
	Mt. hemlock/grouse huckleberry								
	(Percent of stocked subplots)								
Advance	0.2	13.3	0.5	--	10.2	5.1	--	7.6	36.9
Natural subsequent	0.5	9.5	3.7	0.2	3.4	5.5	0.2	8.8	31.8
Planted	--	0.2	1.1	--	--	1.9	9.4	18.7	31.3
Total	0.7	23.0	5.3	0.2	13.6	12.5	9.6	35.1	100.0
	Mixed conifer/snowbrush-chinkapin								
	(Percent of stocked subplots)								
Advance	1.4	0.6	--	--	--	--	--	--	2.0
Natural subsequent	6.9	0.9	--	1.2	--	0.9	0.6	5.5	16.0
Planted	--	--	--	6.2	--	--	75.8	--	82.0
Total	8.3	1.5	--	7.4	--	0.9	76.4	5.5	100.0

[1/] Based on 4-milacre subplots. One- and 2-year seedlings included.

Relation of Present Stocking to Environmental Factors

The influence of observed environmental factors on regeneration and their relative importance in describing present stocking were determined by stepwise regression analyses. The results of these analyses are presented in table 7, which shows the positive or negative relationship to stocking and the order in which variables appeared in the equations.

In the mountain hemlock clearcuts, both grass and forbs have a consistent negative relationship to stocking of all species or classes; in other words, the more grass or forbs present the less regeneration. Except for lodgepole pine and white pine, grass was always one of the first three variables in these equations (table 7). As expected, aspect always appeared as a positive term indicating regeneration generally was greater on more northerly aspects. An increase in elevation resulted in less regeneration, but this variable usually entered as one of the last factors. In most equations, burning (pile and burn) had a negative effect on establishment of regeneration. This agrees with the work of Vogl and Ryder (1969) who reported 80-percent-less reproduction on severe burns than on unburned areas in the mixed conifer type in Montana.

Effect of most factors is logical and has reasonable biological explanations. An exception is the effect of distance from timber. In all equations where it appeared, it was a positive term thus indicating greater stocking as distance from the clearcut edge increased, contrary to the usual expectation of less regeneration. An examination of its single variable relationship to stocking, however, showed that within the 8-chain distance from the timber edge that was sampled in this survey, there was essentially no difference in stocking of natural regeneration (r=.001). Therefore, this variable could appear with a positive or negative sign depending on the combination of variables involved in the regression. Lack of correlation between distance from clearcut edge and stocking within limited distances from edge of the stand has also been reported by Franklin (1963) in western Cascade clearcuts.

The effect of these variables on stocking depends upon the species and origin of reproduction and the plant community. It is also evident that in some cases where there is essentially no relationship between stocking and a single variable, the influence of this variable in a specific regression equation may be opposite of its effect in the single variable correlation. If we keep these inconsistencies in mind, the general effect of these variables on stocking in the mountain hemlock and mixed conifer communities can be summarized by listing those associated with increased stocking, decreased stocking, or having no strong relationship to stocking as follows:

MOUNTAIN HEMLOCK COMMUNITY

Increased stocking	*Decreased stocking*	*Little relationship*
More northerly aspects	More grass	Age of clearcut
More litter and slash	Increased severity of burn	Elevation
	More forbs	Slope
		Mineral soil
		Woody vegetation
		Distance to timber

Table 7--Positive and negative correlations of variables and order in which they appeared in regression equations describing stocking of regeneration in the Cascades by plant community

Species or origin class	Variable[1/]														
	Age	Elevation	Aspect	Slope	Mineral soil	Litter	Slash	Litter and slash	Burn (pile and burn)	Forbs	Woody	Grass	Distance from timber	R^2	Standard error of stocking percent
							Mountain hemlock/grouse huckleberry								
All regeneration	[2/]-6	-5	+3	--	--	--	--	--	-2	-4	--	-1	--	0.75	14.6
All natural regeneration	--	-5	+4	--	--	--	--	--	-2	-3	--	-1	--	.76	15.8
3+ years old	+2	-5	--	--	--	--	--	+1	--	--	--	-3	+4	.72	13.5
1 & 2 years old	-2	--	+5	--	--	--	--	-7	-6	-4	--	-1	+3	.80	10.6
All true fir	--	--	+5	--	--	--	--	+3	-2	--	-4	-1	--	.67	16.1
Subsequent true fir	+5	--	--	--	--	--	--	+1	--	--	-4	-3	+2	.59	10.3
All white pine	+2	--	+1	--	-4	--	--	--	--	-6	-5	-3	--	.65	8.3
Subsequent white pine	+2	--	+1	--	--	--	--	+3	--	--	-4	--	--	.43	8.3
All lodgepole pine	--	--	+2	-3	--	--	--	--	-1	-4	--	--	--	.44	13.6
Subsequent lodgepole pine	+1	--	+4	--	--	-3	--	--	-2	-5	--	--	--	.38	11.5
All Mt. hemlock	--	--	--	--	-4	--	--	--	--	-3	--	-2	+1	.55	9.5
Subsequent Mt. hemlock	--	--	--	-2	--	--	--	--	--	-5	+4	-3	+1	.57	5.4
							Mixed conifer/snowbrush-chinkapin								
All regeneration	--	--	--	--	--	--	--	-4	-2	+5	-1	-3	--	.76	7.1
All natural regeneration	--	+4	--	--	--	-1	-5	--	-2	--	--	-3	+6	.86	10.1
3+ years old	--	+3	--	+5	+6	--	--	--	-1	--	--	-2	+4	.88	7.6
1 & 2 years old	+7	--	--	-4	--	-1	--	-3	-2	+5	+6	--	--	.86	9.6
All true fir	-3	--	-5	--	--	--	--	--	-1	--	--	-2	+4	.80	8.1
Subsequent true fir	--	--	--	+5	+6	--	+2	--	-1	--	--	-3	+4	.82	7.1

[1/] Only those variables which accounted for the major portion of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 4 percent.

[2/] Numbers indicate the order in which variables entered the regression equation.

MIXED CONIFER COMMUNITY

Increased stocking	*Decreased stocking*	*Little relationship*
None	More grass	Age of clearcut
	Increased severity of burn	Elevation
	More litter	Slope
		Mineral soil
		Litter and slash
		Distance to timber
		Aspect
		Forbs
		Slash
		Woody vegetation

Prediction Equations

Reliable equations to predict stocking after clearcutting would be useful. The regression equations summarized in the preceeding section include variables such as grass, forbs, and woody vegetation which change with time similar to the change in stocking and therefore can not be used for predictive purposes. To derive prediction equations, I used only those variables that remain independent and can be measured before or directly after harvest. Variables used were age of clearcut, elevation, aspect, slope, slash, degree of burn, and distance to timber. Strictly speaking, amount of slash and degree of burn do not remain completely unchanged over time but within the time span this study covers they changed very little.

Accurate prediction of regeneration using the six equations developed for the mountain hemlock clearcuts appears unlikely because of the large amount of unexplained variation present. The equation predicting stocking of all 1- and 2-year-old seedlings accounted for the most variation (61 percent) while the white pine and lodgepole pine equations accounted for the least and were not significant (table 8). As expected, aspect always appears as a positive term indicating greater stocking on northerly aspects and burn generally appears as a negative term similar to results of the previous section of this paper. The equation for subsequent true fir in the mixed conifer clearcuts (table 9) was the one accounting for the largest amount of variation (78 percent) in stocking percent.

Although the predictive accuracy of these equations is less than desired, it is probably as good as can be expected considering the variables involved and complex distribution pattern of natural regeneration. Unexplained variation exists for several reasons. In a survey study, no estimate of the amount of seedfall on the clearcuts is obtainable. In addition, factors measured (aspect, slope, etc.) are secondary variables. These variables influence the five primary variables (light, temperature, moisture, chemical, and physical factors) to which seedlings respond directly. Finally, it should be mentioned that, ideally, equations such as these should be checked on an independent set of data not used in their derivation. Therefore, I want to emphasize that in no way should these equations be considered as precise predictors of expected regeneration after clearcutting but only as crude estimates of possible stocking.

BLUE MOUNTAINS

Regeneration Stocking and Density

Clearcuts in the grand fir/big huckleberry community in the Blue Mountains had adequate regeneration. Total stocking averaged 51 percent on milacre subplots with a range of

Table 8--Prediction equations for stocking of regeneration on clearcuts in the Oregon Cascade mountain hemlock/grouse huckleberry community by species and class of reproduction

Dependent variable	Equation[1]	Percent of variation explained R^2	Standard error estimate (percent) sy.x
All natural subsequent Stocking percent	= 34.08 + 4.28 (aspect) - 44.90 (burn) - 2.00 (age) - 4.29 (slope)	0.55	18.4
1- & 2-year-old Stocking percent	= -44.84 - 2.86 (age) + 2.83 (aspect) - 18.69 (burn) - 5.49 (slope) + 0.01 (elev.)	.61	14.5
Subsequent true fir Stocking percent	= 122.15 - 29.77 (burn) - 0.02 (elev.) + 4.21 (slope) + 0.82 (aspect)	.43	11.9
Subsequent white pine Stocking percent	= 30.69 + 0.93 (aspect) + 0.71 (age) - 0.01 (elev.) - 2.41 (slash)	.30^{NS}	9.2
Subsequent lodgepole Stocking percent	= 0.06 + 0.83 (age) - 16.39 (burn) - 3.03 (slope) + 0.78 (aspect)	.32^{NS}	11.8
Subsequent Mt. hemlock Stocking percent	= -8.31 + 0.90 (aspect) + 2.23 (distance) - 1.62 (slope)	.40	6.1

---

[1] Variables are arranged in the order they entered the regression. Only variables which accounted for major portions of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 4 percent.

Table 9--Prediction equations for stocking of regeneration on clearcuts in the Oregon Cascade mixed conifer/snowbrush-chinkapin community by species and class of reproduction

Dependent variable	Equation[1]	Percent of variation explained R^2	Standard error estimate (percent) sy.x
All natural subsequent Stocking percent	= 112.96 + 7.24 (slash) + 4.22 (distance) - 133.99 (burn) - 5.45 (age)	.57^{NS}	16.3
1- & 2-year-old Stocking percent	= 59.70 - 4.87 (age) - 117.19 (burn) - 8.22 (slope) + 0.01 (elev.)	.62	13.2
Subsequent true fir Stocking percent	= 21.59 = 78.90 (burn) + 3.11 (slash) + 0.59 (aspect) + 5.13 (distance) + 6.24 (slope) - 1.78 (age)	.78	7.8

---

[1] Variables are arranged in order they entered the regression. Only variables which accounted for major portions of variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 4 percent.

12 to 96 percent (table 10), about the same as average stocking in the Cascade region. On a 4-milacre basis, total stocking in Blue Mountain clearcuts averaged 81 percent.

Advance reproduction played a relatively minor role in these clearcuts, comprising the smallest regeneration component in both stocking and trees per acre (table 10) because of losses due to logging and slash treatment (mostly broadcast burning). The largest single component was 3-year and older natural regeneration averaging 1,135 stems per acre and found on 34 percent of the subplots. While planted trees averaged only 240 per acre, they occurred on 21 percent of the milacres because of their good distribution.

As in the Cascades, the presence of 1- and 2-year-old seedlings raised density levels but did not change stocking to any large extent. Their presence increased stocking on 40 percent of the plots, but on only 2 of the 50 plots was the gain 12 percent or greater. On one of the two plots, stocking increased by 12 percent and on the other by 16 percent.

The same exponential relationship between density of regeneration and stocked milacres was found on the Blue Mountain plots as well as the Cascades (fig. 4).

Distribution of plots into various stocking classes showed that 66 percent of the plots were at least 40 percent stocked and 56 percent had at least 700 trees per acre 3 years and older (table 11). On some plots, overstocking rather than understocking was the problem. For example, considering total number of trees of all species, seven plots had more than 4,000 trees per acre;

Table 10--Average stocking percentage and number per acre, with standard errors, of all species on clearcuts in the eastern Oregon Blue Mountains, grand fir/big huckleberry plant community by class of reproduction (based on 1-milacre quadrats)

Class of reproduction	No. plots	Mean±S.E.	Range
		Stocking percent	
Advance	50	5.8±1.3	0-48
Subsequent			
1 & 2 year	50	13.0±2.5	0-64
3+ year	50	34.1±3.5	0-88
Planted	50	21.2±1.8	0-48
All classes except 1 & 2 year	50	48.7±2.8	12-88
All classes	50	51.4±3.1	12-96
		Number per acre	
Advance	50	82.0±26	0-920
Subsequent			
1 & 2 year	50	513±179	0-6040
3+ year	50	1135±225	0-8560
Planted	50	240±25	0-840
All classes except 1 & 2 year	50	1457±231	120-8720
All classes	50	1970±382	120-14760

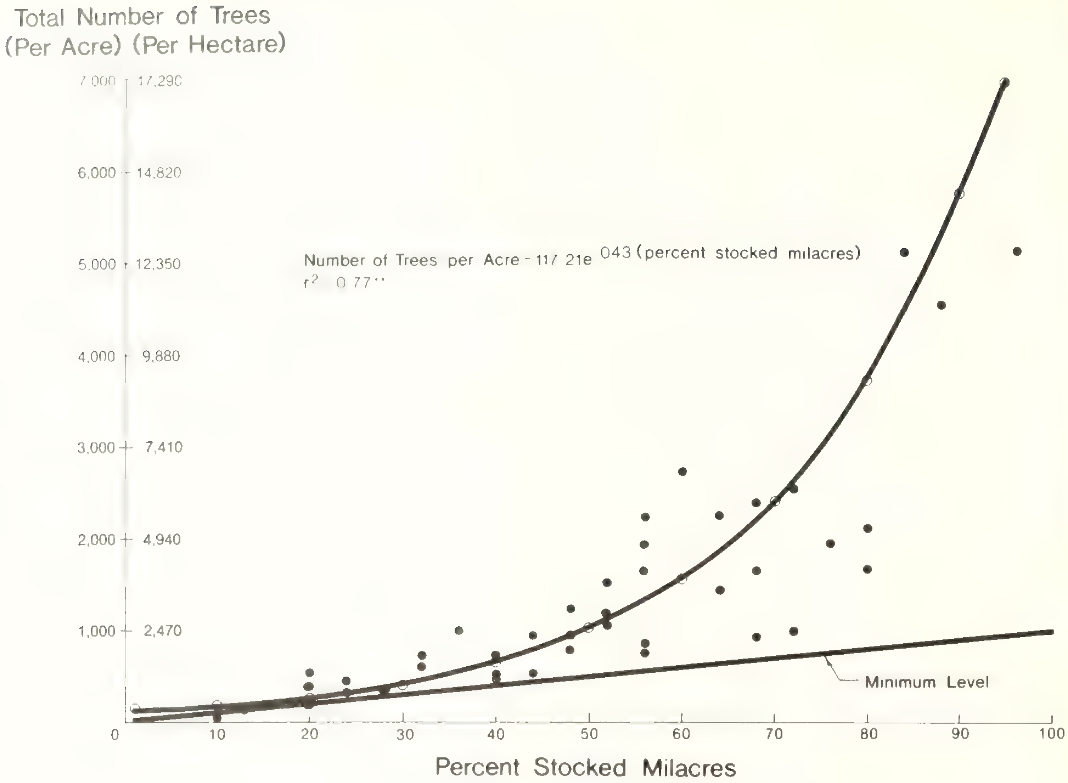


Figure 4.--Relationship of 1-milacre stocking percent to total number of trees per acre for all 50 plots in the Blue Mountains. The minimum level curve indicates the expected relationship if there were no more than one tree per stocked milacre.

Table 11--Proportion of clearcut plots in the eastern Oregon Blue Mountains stocked at various levels with 3-year and older regeneration (advance and subsequent)[1]

Stocking percent			Number trees/acre		
Minimum stocking	Samples	Proportion of total	Minimum stocking	Samples	Proportion of total
Percent	Number		No./acre	Number	
20	49	0.98	200	49	0.98
40	33	.66	400	40	.80
60	19	.38	700	28	.56
80	4	.08	1,000	21	.42
			2,000	10	.20
			3,000	6	.12

[1] Based on 1-milacre quadrats. Total number of sample plots = 50.

the greatest density was 14,670 on one plot.

Species Composition of Regeneration

As expected, regeneration on these clearcuts consisted of a number of species. Grand fir and Engelmann spruce were the two most common species, occurring on 29.8 and 17.1 percent of the subplots (table 12). Ponderosa pine was the third major species and smaller amounts of Douglas-fir, lodgepole pine, and western larch were also present. For all species, the 3-year and older component made up the largest part of the regeneration.

Ponderosa pine was the predominant planted species. It was planted on 47 of the 50 plots and accounted for essentially 100 percent of ponderosa pine regeneration. All of the other species except western larch and lodgepole pine were also planted to some extent--Douglas-fir and Engelmann spruce most often. Douglas-fir was planted on 15 plots and accounted for 40 percent of all surviving Douglas-fir on these plots, but only 4 percent of all species. Spruce was planted on six plots and grand fir on nine; planted trees made up about 10 percent of each species and 5 percent of all reproduction.

In the Blue Mountains, no significant relationship was found between stocking of planted ponderosa pine and elevation. Only a slight downward trend in stocking occurred as elevation increased, but an increasing amount of snow damage was observed at elevations above 5,300 feet.

Dominant Species

All six species found on these clearcuts were dominant on at least 7 percent of the stocked subplots (table 13). Because of its wide distribution, planted ponderosa pine was the predominant species--occurring on 43 percent of the quadrats. Grand fir and lodgepole pine were dominant on 18.3 and 13.9 percent of the subplots, respectively; most of these were of natural subsequent origin.

Just as on Cascade plots, consideration of dominant tree in addition to total numbers or stocking gives a clearer picture of future stand composition. For example, even though ponderosa pine averaged only 180 per acre compared to 3 to 5 times as many fir and spruce, planted pine clearly dominanted because of its good distribution and rapid growth.

Table 12--Average stocking percentage, with standard errors, of advance and subsequent regeneration on clearcuts in the eastern Oregon Blue Mountains by species

Species	Advance	Subsequent		All classes
		3 years & older	1 & 2 years old	
	- - - - - - - - - Stocking percent±S.E. - - - - - - -			
Grand fir	3.4±0.9	27.1±3.0	7.9±1.5	29.8±2.9
Douglas-fir	0.3±0.2	9.0±2.1	2.2±1.2	9.2±2.1
Western larch	0.5±0.2	6.8±1.3	0.5±0.3	7.1±1.3
Engelmann spruce	1.1±0.5	16.3±2.9	6.1±1.9	17.1±2.9
Ponderosa pine	0.0± --	14.9±1.9	0.3±0.2	14.9±1.9
Lodgepole pine	1.1±0.6	8.2±2.5	2.8±1.1	9.1±2.6

Table 13--Species and origin of dominant trees on eastern Oregon Blue Mountain clearcuts[1/]

Origin	Species						
	Grand fir	Douglas-fir	Western larch	Engelmann spruce	Ponderosa pine	Lodgepole pine	Total
	- - - - - - - - - - - - - - - - - - - Percent of stocked subplots - - - - - - - - - - - - - - - - - - -						
Advance	6.2	0.5	0.6	2.0	--	0.3	9.6
Natural subsequent	11.1	2.9	6.8	4.8	0.1	13.6	39.3
Planted	1.0	3.3	--	3.7	43.1	--	51.1
Total	18.3	6.7	7.4	10.5	43.2	13.9	100.0

[1/] Based on 4-milacre subplots. One and 2-year seedlings included.

Relation of Present Stocking to Environmental Factors

In the Blue Mountain plots, fewer variables generally accounted for most variation in stocking and there was a more consistent positive or negative correlation between species or origin classes and environmental factors (table 14). Elevation and slope were the two variables most strongly related to stocking; both in a positive manner. It is interesting that greater stocking was definitely associated with higher elevations contrary to results in Cascade clearcuts. Increased stocking at higher elevations consisted of an abundance of spruce, grand fir, and lodgepole pine natural regeneration. Aspect was again positively correlated to stocking in most regressions, and grass was generally a negative factor in regeneration occurrence. Forbs entered some equations as a positive factor, but single variable correlation showed it to be weakly related to stocking in a negative manner.

Although degree of burn did not contribute much to explained variation, it was positively correlated with stocking in contrast to negative correlation on the Cascade plots. Although no direct evidence is available from this study, it is interesting to speculate that perhaps this difference in effect may, in part, be due to difference in method of burning--pile and burn in the Cascades vs. broadcast burn in the Blue Mountains.

The Douglas-fir and larch equations were the only equations where mineral soil accounted for a large part of the variation in stocking (table 14). For Douglas-fir, it was the first variable entered and it showed a strong positive correlation with stocking; while for larch, a very weak positive correlation existed but it appeared in the equation as a negative term. It is widely recognized that mineral soil is a desirable seed bed. Surface temperatures are lower on mineral soil than on heavy litter and duff layers (Gordon 1970), and mineral soil is a more stable water source. The advantages of a mineral soil seed bed have been clearly shown in studies where such a treatment was compared with other seed beds and other factors were held more or less constant. Seedlings, however, are able to become established in moderate layers (1/2- to 1-inch) of organic matter. In fact, Ryker (1975) reported more natural regeneration of Douglas-fir on litter-covered seed beds than on mineral soil in the Intermountain region. In my study, where many variables are related in a complex pattern, mineral soil was not a major factor in describing the occurrence of regeneration.

Table 14--Positive and negative correlations of variables appearing in regression equations describing stocking of regeneration in the Blue Mountains

Species or origin class	Variable[1/]														
	Age	Elevation	Aspect	Slope	Mineral soil	Litter	Slash	Litter and slash	Burn (broadcast)	Forbs	Woody	Grass	Distance from timber	R^2	Standard error in stocking percent
All regeneration	--	[2/]+2	+5	+1	--	--	+6	--	+4	--	--	-3	--	0.55	15.7
All natural regeneration	--	+2	+4	+1	--	--	--	--	--	+3	--	--	--	.47	19.4
3 years & older	--	+2	+3	+1	--	--	--	--	--	+4	--	--	--	.49	18.3
1 & 2 years	--	+1	--	+3	--	--	--	--	--	--	--	-2	--	.51	12.8
All grand fir	--	+4	+3	+1	--	--	--	--	--	--	--	-2	--	.40	16.8
Subsequent grand fir	--	+4	+2	+1	--	--	--	--	--	--	--	-3	--	.39	17.1
1 & 2 year grand fir	-4	+1	--	+2	--	--	--	--	--	--	--	-3	--	.40	8.8
All spruce	--	+1	+2	--	--	--	--	--	--	--	-4	-3	--	.43	16.0
Subsequent spruce	--	+1	+2	--	--	--	--	--	+4	--	--	-3	--	.45	15.[illegible]
All larch	--	+2	+4	+1	-3	--	--	--	--	--	--	--	--	.33	7.[illegible]
Subsequent larch	--	+2	+4	+1	-3	--	--	--	--	--	--	--	--	.45	[illegible]
All Douglas-fir	--	+5	+3	+2	+1	--	--	--	--	+4	--	--	--	.60	[illegible]
Subsequent Douglas-fir	--	+4	+3	+2	+1	--	--	--	--	+5	--	--	--	.61	[illegible]

[1/] Only those variables which accounted for the major portion of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

[2/] Numbers indicate the order in which variables entered the regression equation.

In the Blue Mountain region, the environmental variables are generally related to stocking as follows:

Increased stocking	Decreased stocking	Little relationship
Higher elevation	More grass	Age of clearcut
More northerly aspect		Mineral soil
Greater slope		Litter and slash
Increased severity of burn		Forbs
		Woody vegetation

Animal damage of any kind was light on both Blue Mountain and Cascade plots. Gopher activity was observed on only 2 percent of the subplots in Blue Mountain clearcuts and on 1 percent in the Cascades. Occasional ponderosa pine saplings were damaged by porcupines.

Prediction Equations

Less than one-half of the variation in stocking was explained by prediction equations developed for Blue Mountain plots; ranging from 31 percent for the subsequent larch equation to 49 percent for all 1- and 2-year-old seedlings (table 15). Except for the burning variable in the first equation, only aspect, slope, and elevation strongly correlate with stocking. As expected, these three variables appear in all equations as a positive term just as they do in equations describing present stocking.

Conclusions and Recommendations

Survey results provide a broad overview of regeneration status on clearcuts in upper slope mixed conifer forests of the eastern Cascades and Blue Mountains. Such information is useful in evaluating harvesting methods, discovering differences in

Table 15--Prediction equations for stocking of regeneration on clearcuts in the Oregon Blue Mountains by species and class of reproduction

Dependent variable	Equation[1/]	Percent of variation explained R^2	Standard error estimate (percent) $s_{y.x}$
All natural subsequent Stocking percent	= -43.27 + 12.83 (slope) + 0.01 (elev.) + 1.24 (aspect) + 14.05 (burn)	0.47	20.1
1- & 2-year-old Stocking percent	= -72.86 + 0.02 (elev.) + 3.86 (slope) + 0.64 (aspect)	.49	13.0
Subsequent grand fir	= 6.68 + 10.34 (slope) + 1.13 (aspect)	.34	17.5
Subsequent Douglas-fir	= -50.92 + 0.01 (elev.) + 4.32 (slope) + 0.87 (aspect)	.46	11.0
Subsequent larch	= -14.10 + 3.93 (slope) + 0.003 (elev.) + 0.34 (aspect)	.31	8.0
Subsequent spruce	= -72.54 + 0.02 (elev.) + 1.43 (aspect)	.40	16.2

[1/] Variables are arranged in the equation in the order in which they entered the regression. Only those variables which accounted for the major portion of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

regeneration between plant communities, and identifying problem areas. I want to emphasize, however, that these results are broad averages and do not indicate the precise regeneration picture on any specific National Forest or Ranger District within the study area. Also, I would like to point out that the purpose of the survey was to compare and evaluate regeneration that has developed on mixed conifer clearcuts and is *not* to be considered as a recommendation for use of this silvicultural system to exclusion of others.

Generally, reforestation on these clearcuts has been quite satisfactory. The combination of advance, natural subsequent, and planted reproduction has resulted in adequate stocking on most of the clearcuts surveyed, and in overstocked conditions on some. It should be noted here that generally the forester's attention is focused on problems of establishing regeneration and too often the problem of an overabundance of trees is neglected. The early implementation of stocking level control is especially important for seral species such as larch and lodgepole pine where crowns quickly decrease in size and growth is lost if thinning is delayed.

Advance reproduction played a significant role in the Cascade mountain hemlock clearcuts where slash was not treated. Many mature stands in this plant community have a well-stocked understory of true fir and mountain hemlock saplings and poles. Even though suppressed for many years, vigorous, fully crowned understory trees will respond to release (Seidel 1977). It was evident that advance reproduction *can* be saved if felling and skidding operations are planned to minimize damage to the understory. Barrett et al. (1976) have shown it is possible to save sufficient numbers of ponderosa pine understory during logging and slash disposal to form the new stand by marking understory crop trees before harvest and using unconventional slash disposal methods. Such techniques should be applicable to mixed conifer stands where topography permits.

Natural regeneration established after clearcutting generally resulted in considerable numbers of seedlings, although in many cases distribution was patchy and seedlings were overtopped by brush. Despite the presence of many seedlings of natural origin on these clearcuts, relying on natural regeneration as the primary method of regenerating mixed conifer clearcuts is not recommended when intensive forest management is practiced. There is no assurance that natural regeneration will occur within any specific time period because of many factors such as seed supply and microclimate which are beyond the forester's control. If significant amounts of grass invade the clearcut before a good seed year occurs, probability of seedling establishment will decrease. In this study, woody vegetation (snowbrush, manzanita) was not a negative factor in seedling establishment but severely reduced growth of young trees.

In clearcuts where no advance reproduction exists or where it has been destroyed in the logging and slash disposal operations, planting is the obvious choice for stand establishment rather than relying on natural regeneration. Planting promptly restores the area to timber production before it is taken over by grass or woody vegetation, and enables the land manager to choose spacing to meet his objectives. At elevations below about 5,300 feet, ponderosa pine is clearly the preferred species to plant because its good survival and rapid growth rate result in full site utilization within a short period. In such plantations, ponderosa pine will be dominant for many years but in the long run a typical mixed conifer stand will result because of natural regeneration of other species and the trend of succession to more shade tolerant species. In higher elevation clearcuts, lodgepole pine is a desirable species to plant because of its greater resistance to snow damage. In the Blue Mountains, western larch appears to be a promising species to plant in higher elevation clearcuts, although surprisingly little larch has been planted in this area.

Establishment of mixed species plantations also reduces the chance of losing an entire plantation to insect or disease attacks. Of course, establishment of successful plantations is not a simple matter. It involves a complex series of operations including correct seed source, production of vigorous nursery stock, proper lifting, handling, and storage of stock, careful planting procedures, and animal damage control. It is beyond the scope of this paper to discuss details of these many and varied operations. All regeneration foresters, however, would be well advised to read guidelines for plantation establishment prepared by Cleary et al. (1978).

In clearcuts where advance reproduction provides almost adequate stocking, natural regeneration could augment this stocking by filling in holes created by skid trails and slash disposal operations. If natural regeneration is used to supplement advance reproduction, slash disposal should be minimized. This not only prevents unnecessary destruction of the advance reproduction but some slash on the ground creates a more favorable environment for seedling establishment by moderating temperature extremes. In conclusion, because of the uncertainties associated with obtaining natural regeneration, it seems best suited as a supplemental rather than a primary method of regenerating mixed conifer clearcuts.

Literature Cited

Barrett, James W., Stanley S. Tornbom, and Robert W. Sassaman.
1976. Logging to save ponderosa pine regeneration; a case study. USDA For. Serv. Res. Note PNW-273, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Bever, Dale N.
1949. A study of a stocking survey system and the relationship of stocking percent as determined by this system to number of trees per acre. Oregon State Board For. Res. Bull. 1, 40 p., illus.

Cleary, Brian D., Robert D. Greaves, and Richard K. Hermann (eds.).
1978. Regenerating Oregon's forests--a guide for the regeneration forester. Oregon State Univ. Ext. Serv., Corvallis, Oreg. 286 p., illus.

Day, Frank P., and Carl D. Monk.
1974. Vegetation patterns on a southern Appalachian watershed. Ecology 55:1064-1074, illus.

Franklin, Jerry F.
1963. Natural regeneration of Douglas-fir and associated species using modified clear-cutting systems in the Oregon Cascades. USDA For. Serv. Res. Pap. PNW-3, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gordon, Donald T.
1970. Natural regeneration of white and red fir.....influence of several factors. USDA For. Serv. Res. Pap. PSW-58, 32 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Hall, Frederick C.
1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. USDA For. Serv. Pac. Northwest Region R6 Area Guide 3-1, 62 p., illus.

Harris, A. S.
1967. Natural reforestation on a mile-square clearcut in southeast Alaska. USDA For. Serv. Res. Pap. PNW-52, 16 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Larsen, Daniel M.
1976. Soil resource inventory--Deschutes National Forest. 381 p., illus. USDA For. Serv., Pac. Northwest Reg. [Portland Oreg.]

Lynch, D. W., and F. X. Schumacher.
1941. Concerning the dispersion of natural regeneration. J. For. 39(1):49-51, illus.

Ryker, Russell A.
1975. A survey of factors affecting regeneration of Rocky Mountain Douglas-fir. USDA For. Serv. Res. Pap. INT-174, 19 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Seidel, K. W.
1977. Suppressed grand fir and Shasta red fir respond well to release. USDA For. Serv. Res. Note PNW-288, 7 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Vogl, Richard J., and Calvin Ryder.
1969. Effects of slash burning on conifer reproduction in Montana's Mission Range. Northwest Sci. 43:135-147, illus.

Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. USDA For. Serv. Pac. Northwest Region R6 Area Guide 4-2, 110 p., illus.

Wade, John M.
1975. Soil Resource Inventory--Wallowa Whitman National Forest. 222 p., illus. USDA For. Serv. Pac. Northwest Reg. [Portland, Oreg.]

Wellner, C. A.
1940. Relationships between three measures of stocking in natural reproduction of the western white pine type. J. For. 38(8):636-638, illus.

Appendix

I. Independent (X) variables used in regression analyses.

1--Age of clearcut. The number of years since the area was harvested.

2--Elevation. The average elevation of the plot to the nearest 10 feet as measured with an altimeter.

3--Aspect. One of eight compass points measured on each subplot. Aspect was coded using the method proposed by Day and Monk (1974), in which the following values were assigned to compass directions: N - 14; NE - 15; E - 11; SE - 7; S - 3; SW - 2; W - 6; NW - 10. Average coded value of the 25 subplots was used in analyses.

4--Slope. Percentage slope of each subplot was measured with clinometer and coded as follows: 0-9%......0; 10-19%......1; 20-29%......2; 30-39%......3; etc. Average coded value of subplots used.

5--Mineral soil. The percentage of each subplot containing mineral soil was estimated, coded in the same way as slope values, and averaged.

6--Litter. The percentage of each subplot covered with litter was estimated, coded in the same way as slope values, and averaged.

7--Slash. The percentage of each subplot covered with slash was estimated, coded in the same way as slope values, and averaged.

8--Litter and slash. The percentage of each subplot covered with litter and slash was estimated, coded in the same way as slope values, and averaged.

9--Degree of burn. Estimated on each subplot and coded as None......0; Light......1; Medium......2; Heavy......3. Average coded value used in analyses. Degree of burn definitions are: None--no visible effect of fire. Light--fire charred surface of forest floor but did not remove all of litter layer. Medium--fire removed all of litter layer and some of the duff. Heavy--fire removed all litter and duff and imparted a coloration to the mineral soil.

10--Forbs. The percentage of each subplot covered with forbs was estimated, coded in the same way as slope values, and averaged.

11--Woody perennials. The percentage of each subplot covered with woody perennials was estimated, coded in the same way as slope values, and averaged.

12--Grasses and sedges. The percentage of each subplot covered with grasses and/or sedges was estimated, coded in the same way as slope values, and averaged.

13--Distance to timber edge. The distance from each subplot to the nearest timber edge was estimated to the nearest chain and averaged.

GPO 987-381

Seidel, K. W.
1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of clearcuts in mixed conifer forests of the Cascade Range and Blue Mountains of eastern Oregon showed that, on the average, clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. Planted ponderosa pine dominated clearcuts at elevations of less than 5,300 feet; and at higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present. Seedling establishment was better on more northerly aspects while increasing amounts of grass had a negative effect on stocking.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), Oregon (Blue Mountains), silvicultural systems (clearcutting).

Seidel, K. W.
1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of clearcuts in mixed conifer forests of the Cascade Range and Blue Mountains of eastern Oregon showed that, on the average, clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. Planted ponderosa pine dominated clearcuts at elevations of less than 5,300 feet; and at higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present. Seedling establishment was better on more northerly aspects while increasing amounts of grass had a negative effect on stocking.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), Oregon (Blue Mountains), silvicultural systems (clearcutting).

Seidel, K. W.
1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of clearcuts in mixed conifer forests of the Cascade Range and Blue Mountains of eastern Oregon showed that, on the average, clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. Planted ponderosa pine dominated clearcuts at elevations of less than 5,300 feet; and at higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present. Seedling establishment was better on more northerly aspects while increasing amounts of grass had a negative effect on stocking.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), Oregon (Blue Mountains), silvicultural systems (clearcutting).

Seidel, K. W.
1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of clearcuts in mixed conifer forests of the Cascade Range and Blue Mountains of eastern Oregon showed that, on the average, clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. Planted ponderosa pine dominated clearcuts at elevations of less than 5,300 feet; and at higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present. Seedling establishment was better on more northerly aspects while increasing amounts of grass had a negative effect on stocking.

KEYWORDS: Regeneration (stand), regeneration (natural), regeneration (artificial), mixed stands, Oregon (Cascade Range), Oregon (Blue Mountains), silvicultural systems (clearcutting).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon

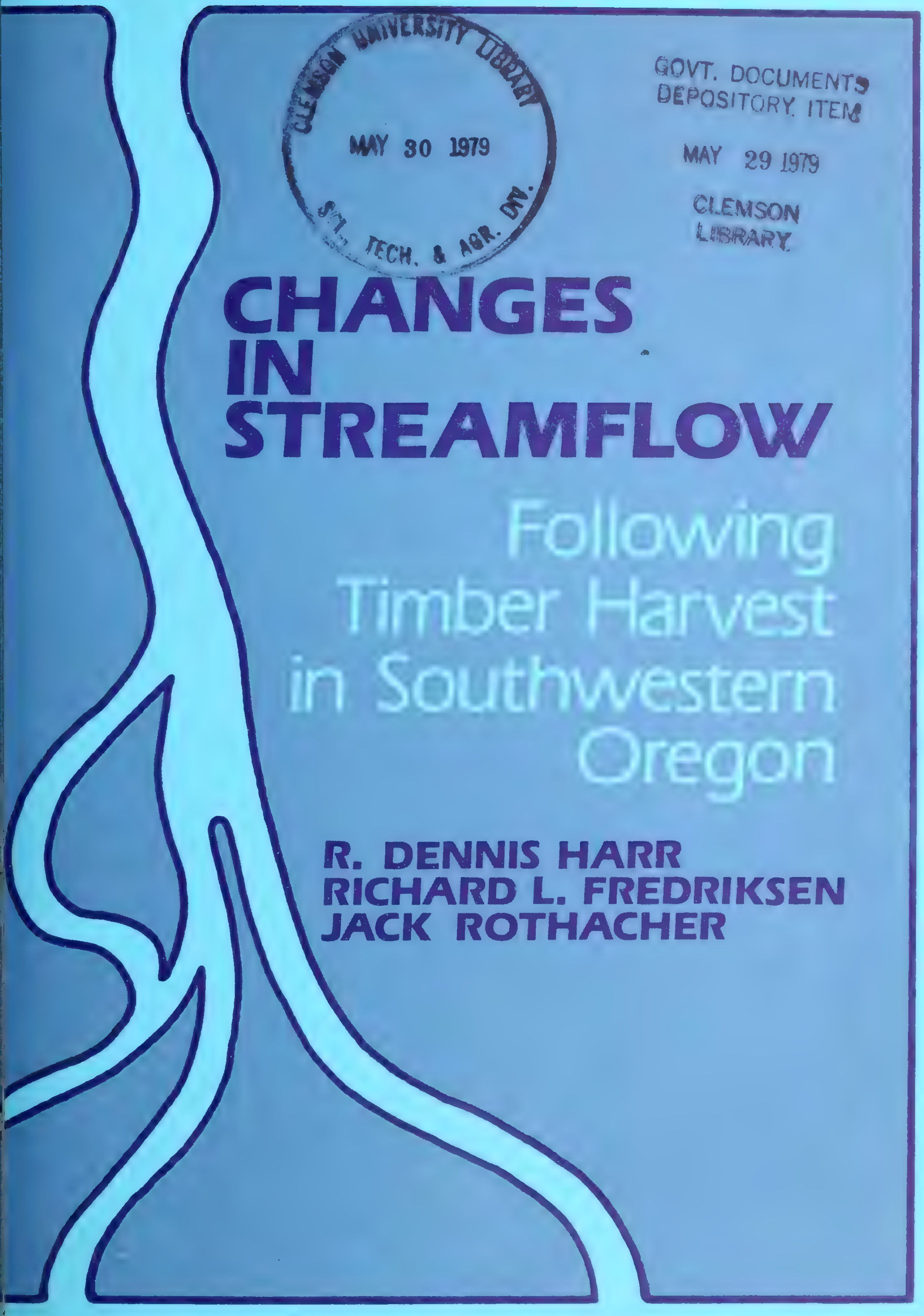
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

RESEARCH PAPER PNW-249
FEBRUARY 1979



CLEMSON UNIVERSITY LIBRARY
MAY 30 1979
SCI., TECH. & AGR. DIV.

GOVT. DOCUMENTS
DEPOSITORY ITEM
MAY 29 1979
CLEMSON
LIBRARY

CHANGES IN STREAMFLOW

Following Timber Harvest in Southwestern Oregon

R. DENNIS HARR
RICHARD L. FREDRIKSEN
JACK ROTHACHER

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

Contents

Page

INTRODUCTION 1

STUDY AREA 1
  Watershed Characteristics. 1
  Climate and Streamflow 3

WATERSHED TREATMENTS 4
  Methods of Data Analysis 7

CHANGES IN STREAMFLOW 8
  Annual Yield 8
  Seasonal Streamflow 10
  Instantaneous Peak Flow 11

DISCUSSION 13
  Water Yield 13
  Peak Flow 15
  Relation to Mass Erosion 19

SUMMARY 20

ACKNOWLEDGMENTS 20

LITERATURE CITED 20

R. DENNIS HARR is Research Hydrologist with the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon.

RICHARD L. FREDRIKSEN is Research Soil Scientist with the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon.

JACK ROTHACHER is deceased. He was formerly Research Hydrologist with the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon.

CHANGES IN STREAMFLOW FOLLOWING TIMBER HARVEST IN SOUTHWESTERN OREGON

Reference Abstract

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in southwestern Oregon. USDA For. Serv. Res. Pap. PNW-249, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

RESEARCH SUMMARY

Research Paper PNW-249

1979

Changes in streamflow after complete clearcutting, small patch clearcutting, and shelterwood cutting were determined for three small watersheds in southwestern Oregon. The first year increase in annual yield was 36 cm (39 percent), and increases averaged 29 cm (43 percent) for 5 years in a watershed that was completely clearcut. Increases averaged 6-9 cm (8-14 percent) in the other logged watersheds. Largest absolute increases occurred in winter, whereas largest relative increases generally occurred during fall and summer when maximum differences in soil water content existed between cut and uncut watersheds. Increases in size of instantaneous peak flow appear related to the proportion of a watershed where soil had been compacted during logging and slash disposal. Size of peak flow was increased most in the shelterwood cut watershed where soil was compacted on about 13 percent of the area. Effects of soil disturbance on peak flow may have significance for erosion and for culvert design in headwater areas and for sedimentation downstream, but probably are of little importance for flooding of lowlands downstream. Increases in annual water yield under sustained yield forest management will not augment water supplies appreciably in southwestern Oregon.

Introduction

Shelterwood cutting and small patch clearcutting have been proposed to overcome problems of reforestation in the mixed-conifer zone of southwestern Oregon. In 1962, a study was begun to determine changes in quantity and quality of streamflow following these two harvest methods and to compare them with changes caused by complete clearcutting. Specifically, the objectives of this study are to determine increases in size of annual yield, seasonal yield, and peak streamflow after timber harvest. This report describes changes in streamflow following the first of three phases of timber harvest. Water quality changes will be described in a subsequent report.

That cutting forest vegetation increases streamflow has been known for some time, although the size and duration of increases are known for only a few local areas. Taken collectively, however, water yield improvement studies indicate the range in size of increases that can be expected in various regions (Hibbert 1967). In the maritime climate of western Oregon, two such studies have shown that clearcut logging of entire small watersheds in mountainous topography of the Coast and western Cascade Ranges can cause absolute increases in annual yield that are among the largest in the world (Rothacher 1970, Harris 1973, Harr 1976). Increases in size of peak flows have also been related to timber harvest activities in western Oregon (Rothacher 1973, Harris 1973, Harr et al., 1975). Changes in streamflow have been due to both reduced evapotranspiration which makes more water available for streamflow, increased overland flow caused by soil compaction during roadbuilding, logging, and slash disposal, and interception of subsurface flow by roadcuts and ditches.

Mixed conifer forests cover approximately half of the five-county area making up southwestern Oregon and also extend well into northern California. Old-growth forests contain valuable timber which supports the most economically important industry in the region. These watersheds also yield a major portion of irrigation water for agriculture, the region's number two industry. Streams are also important as spawning and rearing areas for anadromous and resident fish. Natural, low summer streamflow, the demand for irrigation water, and runoff-erosion relationships have made forest-streamflow relations of prime interest and concern to land managers and water resource planners in this region (Hayes 1959, Hayes and Herring 1960).

Study Area

WATERSHED CHARACTERISTICS

The four Coyote Creek Experimental Watersheds are located about 55 km southeast of Roseburg, Oregon, at the head of Coyote Creek, a small tributary of Buckeye Creek which flows into the South Umpqua River. Watersheds range in size from 48.6 to 69.2 ha and generally have well-defined boundaries (fig. 1). Watershed aspect ranges from east-northeast for CC-1 (Watershed 1) to north for CC-3. Elevation of the watersheds ranges from 730 to 1 065 m above mean sea level.

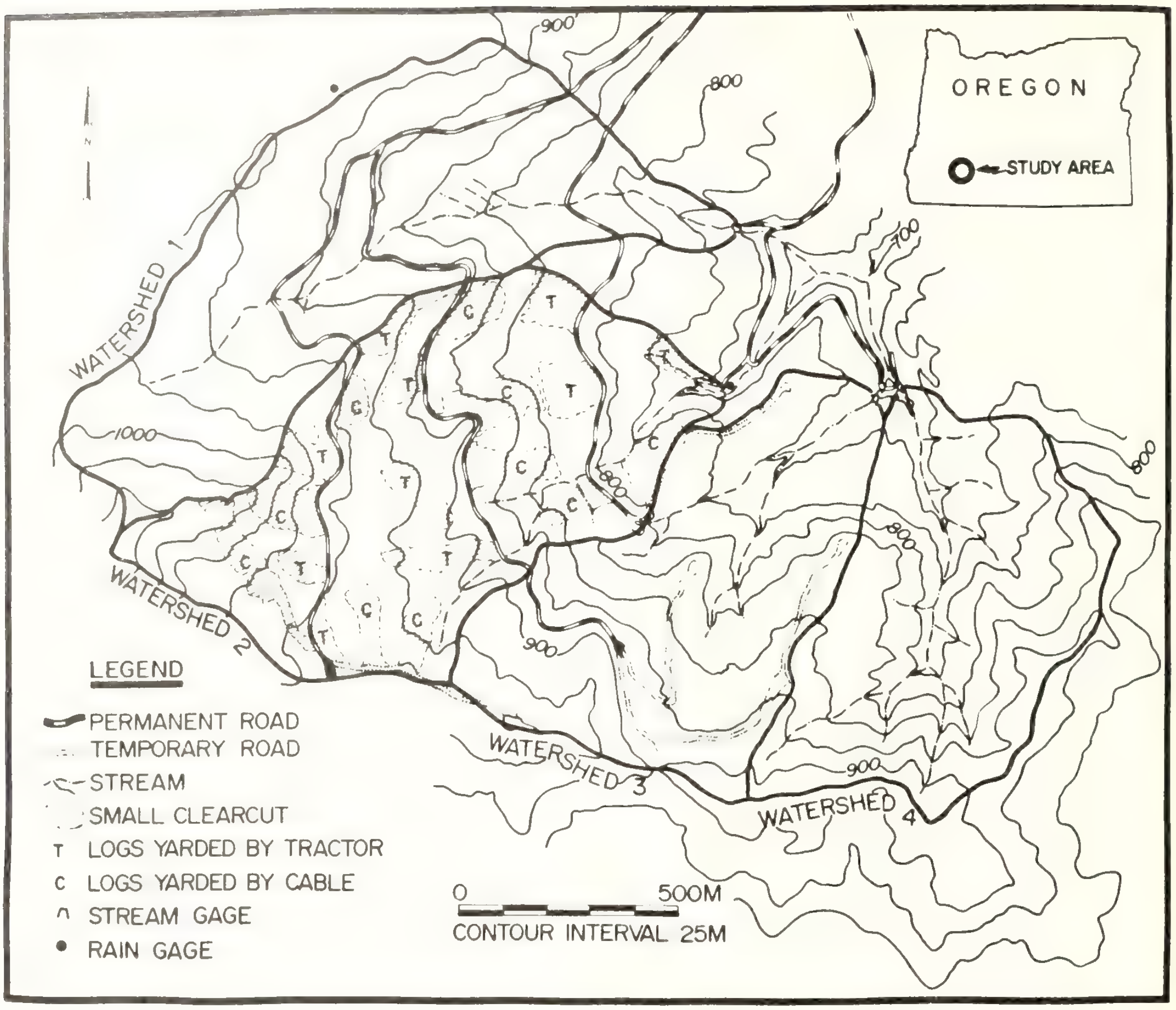


Figure 1.--Map of Coyote Creek Experimental Watersheds.

The watersheds are underlain by the Little Butte Formation, rhyodacitic pyroclastic rocks consisting of welded and nonwelded ash-flow tuffs with andesite and basalt common on ridges (Kays 1970). Although many slopes are relatively smooth, some have poorly developed external drainage patterns that attest to past and present mass erosion processes (Swanson and Swanston 1977). Ranging from 20 to 80 percent, slope gradients of the experimental watersheds are typical of much of the surrounding region.

Two soil series occupy most of the study area (Richlen 1973). Dumont soils are moderately permeable, well-drained gravelly loams at least 150 cm thick, and derived from reddish breccia parent material. Straight soils are similar to Dumont soils but are only 50-100 cm thick. Surface soils of both series have relatively high permeabilities but may be underlain by denser soil layers that impede vertical movement of soil water.

The study area is in the mixed conifer zone (Franklin and Dyrness 1973). Here, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) of the more mesic regions to the north and west is intermingled with ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*Pinus lambertiana* Dougl.), and incense-cedar (*Libocedrus decurrens* Torr.) characteristic of warmer, drier sites. Within the watersheds, more mesic habitats contain western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), grand fir (*Abies grandis* (Dougl.) Lindl.), and big leaf maple (*Acer macrophyllum* Pursh). Before logging, both age class and overstory density varied considerably within a watershed as well as among watersheds.

CLIMATE AND STREAMFLOW

The climate of the study area is influenced by the Pacific Ocean 150 km to the west. Annual precipitation at the climatic station adjacent to CC-2 has averaged 123 cm, ranging from 88 cm to 156 cm (table 1). Winters are cool and wet, and summers are warm and dry. Approximately 89 percent of annual precipitation occurs in the October-March period during long-duration, low intensity frontal storms associated with cyclones which originate over the Pacific Ocean. Locally, precipitation caused by frontal activity is augmented by orographic precipitation when moist, unstable air masses move inland. Average daytime temperatures range from -0.5° to 1-5°C in winter and 15°-20°C in summer (fig. 2).

Table 1--Annual precipitation at the climatic station adjacent to CC-2 and streamflow at control watershed CC-4.

Year	Precipitation	Streamflow at CC-4
	- - - - - Cm	- - - - -
1961	115.2	[1] --
1962	122.1	[1] --
1963	124.7	[1] --
1964	115.7	[1] --
1965	124.4	[2] --
1966	107.8	37.5
1967	118.5	53.2
1968	87.6	18.1
1969	110.9	53.4
1970	116.3	51.6
1971	155.7	89.1
1972	153.3	107.0
1973	89.5	28.9
1974	156.5	106.5
1975	122.6	68.9
1976	145.8	75.8
Mean	122.9	62.7

[1] Streamflow measurement began in December 1, 1963.

[2] Stream gage was inoperative from December 1, 1964 to March 19, 1965.

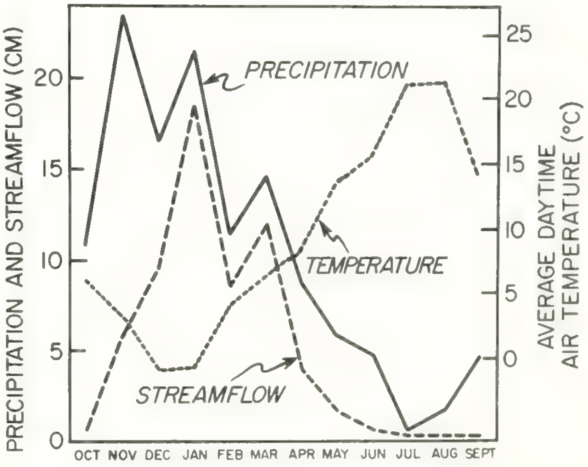


Figure 2.--Monthly precipitation at CC-2 and streamflow at CC-4, 1964-1976, and average monthly daytime air temperature at CC-2, 1970-1973.

Although most precipitation occurs as rain, snow is common, particularly at higher elevations. Occasionally a snowpack may remain for 1-3 months; but in most years, it usually melts within 1-2 weeks. The highest runoff in this region, as in the rest of the Pacific Northwest, has resulted from rapid snowmelt during prolonged heavy rainfall (Waananen et al. 1971, U.S. Army Corps of Engineers 1975).

Streamflow has been measured continuously with 120-degree sharp-crested V-notch weirs (fig. 3) since December 1963. (Streamflow measurements began at CC-1 and CC-2 in 1962, but data prior to December 1963 have been excluded from this study.) Because weir ponds were filled with sediment at CC-1, CC-3, and CC-4 between December 21, 1964 and March 19, 1965, five peak streamflows could not be measured accurately during this period. Data for this period has been excluded from all analyses. An October 1-September 30 water year has been used throughout.

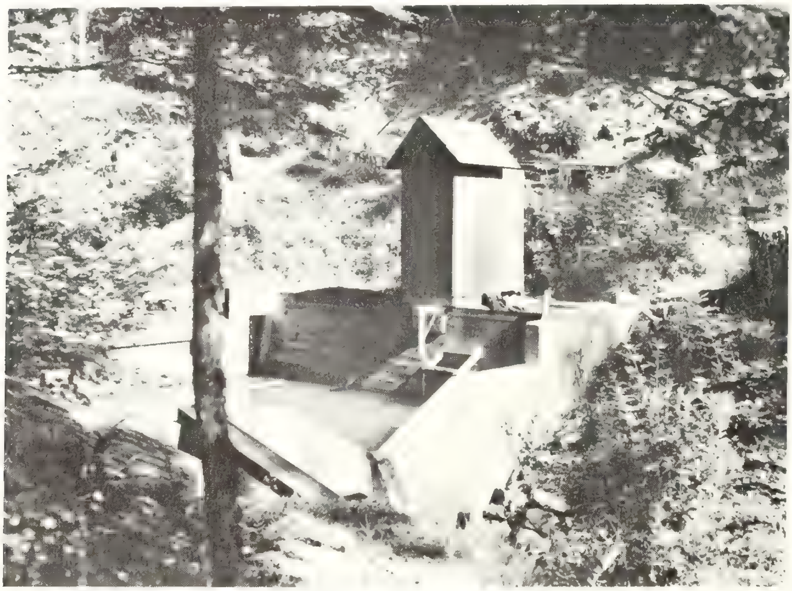


Figure 3.--The 120-degree sharp-crested V-notch weir at CC-1.

During the 1966-1976 period, annual streamflow at CC-4, the control watershed, averaged 63 cm, ranging from 18 to 107 cm. Annual streamflow at this watershed has varied from 21 percent of annual precipitation during 1968, which had the least precipitation of the 11-year period, to about 70 percent during 1972 and 1974, two of the wettest years of the period. Apparent annual evapotranspiration, as estimated from annual precipitation minus annual streamflow adjusted to a unit area basis, has averaged about 61 cm, ranging from 50 cm in 1974 to over 70 cm in 1966. Maximum instantaneous streamflow has been over 4,000 times greater than minimum streamflow.

Watershed Treatments

In this study we used the paired watershed technique. With this technique, a hydrologic variable in one watershed is compared with that in another watershed during the calibration or pretreatment period to establish a relationship between watersheds over a range of climatic conditions. Then one watershed of a pair is treated or altered in some way while the other is left as an undisturbed control. Post-treatment measurements of the hydrologic variable are compared with a prediction of the variable based on the calibration relationship to evaluate changes caused by treatment. Three pairs of watersheds were used in this study.

Road Construction

During the summer of 1970, a system of permanent roads was constructed to provide access for logging (fig. 1). Roads have 5.5-m-wide subgrades and 3.7-m-wide driving surfaces. After subgrade and surface courses were compacted with a vibrating roller, road cutbanks and fill slopes were seeded, mulched, and fertilized in late September (fig. 4). All road construction operations were completed before October 1, 1970.

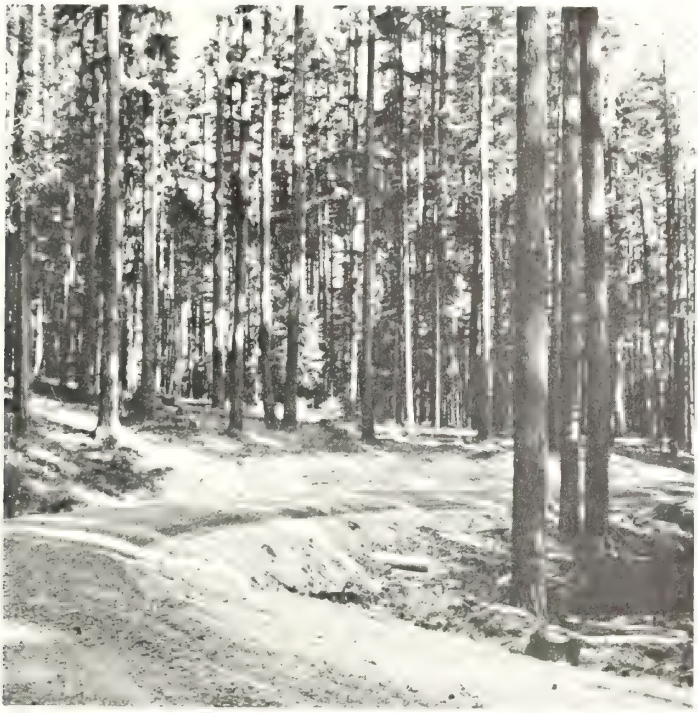


Figure 4.--Newly constructed road with mulched cutbanks and fill slopes in CC-2.

During road construction, 6.4 percent, 7.6 percent, and 1.6 percent of CC-1, CC-2, and CC-3, respectively, were cleared (table 2). All but about 2 percent of CC-1 and CC-2 and 0.3 percent of CC-3 were revegetated a year after seeding. In general, seeding was successful in preventing surface erosion from road cutbanks and fill slopes.

Logging

Logging began in May 1971 and was completed before September 30, 1971. In CC-1, individual trees making up about 50 percent of total basal area were marked for a preparatory shelterwood cut. Timber was cut and removed after spur roads were constructed to tractor landings scattered throughout the watershed. Cull logs were yarded to landings, but slash was left where it fell. When logging was completed, spur roads and landings were scarified and water-barred. Slightly less than half of CC-1 was disturbed to some degree; 13 percent was compacted (table 3). In addition, some road cuts and ditches have intercepted subsurface flow.

Table 2--Summary of treatment areas in Coyote Creek Experimental Watershed

Percents and areas	Watersheds			
	CC-1	CC-2	CC-3	CC-4
Total area (ha)	69.2	68.4	49.8	48.6
Area in permanent roads (ha)	1.1	1.2	.1	0
Percent in permanent roads	1.6	1.7	.3	0
Area logged in 1971 (ha)	[1] 69.2	20.5	49.8	0
Percent logged:	[1] 100	30	100	0
by tractor	[1] 100	14	23	0
by high-lead	0	16	77	0
Slash disposal by tractor (percent)	0	14	23	0
Slash disposal by high-lead (percent)	0	16	77	0

[1] A preparatory shelterwood cut was made throughout the watershed. Approximately 50 percent of total basal area was harvested.

Table 3-- Soil disturbance resulting from yarding and slash disposal. Figures are frequencies of occurrence expressed as percentages of total observations made at 3-m intervals along transects

Disturbance[1]	CC-1 (Shelterwood)	CC-2 (Small patch-cut)[2]			CC-3 (Clearcut)[2]		
	Tractor	Tractor	Cable	Composite[3]	Tractor	Cable	Composite
	Percent[4]						
Undisturbed	52	5	42	25	11	44	34
Slightly disturbed	17	25	39	32	26	29	28
Deeply disturbed	9	30	9	19	25	8	12
Compacted	13	26	6	15	27	7	12
Nonsoil areas	9	13	4	8	11	12	12
Bare soil	11	35	15	24	34	9	15

[1] Slightly disturbed = litter removed and mineral soil exposed, litter and mineral soil mixed, or mineral soil deposited on litter and slash; deeply disturbed = surface soil removed and subsoil exposed; compacted = obvious compaction due to passage of machinery or logs.

[2] "Tractor" and "cable" refer to methods of both yarding and slash removal.

[3] Composite figures were obtained by weighting tractor and cable percentages by percent of logged area where logs were yarded by each method. To obtain composite percentages for the entire watershed, multiply by 0.30, the proportion of the watershed that was logged.

[4] Columns do not add to 100 percent because disturbed areas may also be compacted or bare.

In CC-2, timber was harvested in 20 small clearcut patches ranging in size from 0.7 to 1.4 ha which collectively make up 30 percent of total watershed area. Half the patches, those on more gentle slopes, were logged by tractor whereas other patches were logged with a mobile, high-lead cable system (fig. 1). In the tractor logged units, slash was piled by tractor. Soil was compacted on 26 percent of the tractor logged area; only 5 percent of the tractor logged area remained undisturbed. In the high-lead logged units, soil disturbance was less severe. Soil in 6 percent of logged area was compacted and 42 percent was undisturbed (table 3). Road cuts and ditches have intercepted subsurface flow in several areas in this watershed also.

Timber in CC-3 was completely clearcut after spur roads were constructed across the middle of the watershed and along the central ridge. Several wet areas have been exposed and drained by road cuts and ditches along the uppermost road. Timber on 38 ha (77 percent of the watershed) was clean-logged, i.e. all material >20 cm in diameter and >2.4 m in length was yarded to a high-lead landing (fig. 5). Soil was compacted on only about 7 percent of the clean-logged area and 44 percent was undisturbed (table 3). The use of tractors for yarding and for windrowing slash in the area between the stream and the northwestern boundary of the watershed and in two other smaller areas compacted soil on 27 percent of the area and left only 11 percent undisturbed (fig. 5). Slash piles were burned during the fall of 1973.

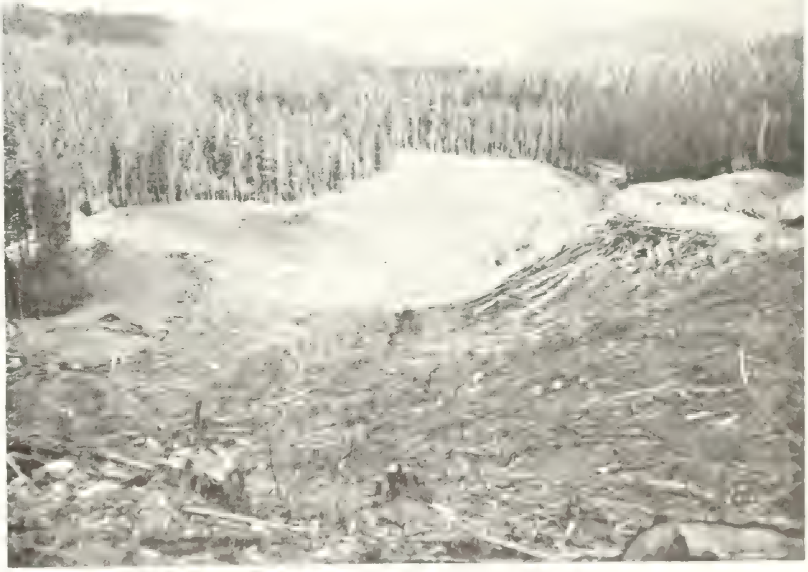


Figure 5.--Seventy-seven percent of CC-3 was clean-logged. All material >20 cm in diameter and >2.4 m in length was yarded to landings one of which is shown at right. Tractor-piled slash on the tractor-yarded northwestern portion of CC-3 is visible in the center of this photograph.

METHODS OF DATA ANALYSIS

Streamflow data were analyzed to determine changes in annual yield, seasonal yields, and instantaneous peak flows after timber harvest. Annual and seasonal yields or flows are total volumes of flow computed for a water year or a season and are expressed as a uniform depth of water over a watershed. Peak flow is the maximum instantaneous streamflow attributable to a particular runoff period and is expressed in liters per second per hectare (liters/sec·ha).

We used simple linear regression to obtain prelogging prediction equations and, for some analyses, postlogging prediction equations. Annual and seasonal flows and instantaneous peak flows at CC-1, CC-2, and CC-3 each were regressed against corresponding flows at CC-4, the control watershed. Each regression analysis is based on the assumption that individual values of a hydrologic variable--either annual flow, seasonal flow, or peak flows--are independent and random. We recognize, however, that independence may not always occur in this type of study.

In the case of annual and seasonal yields, the significance of the difference between prelogging and postlogging data was determined by computing a prediction limit for prelogging conditions. Because timber harvest was expected to increase water yields, we used a one-tailed test for significance of changes in yield at the 0.05 level of probability. Thus, prediction limit is given by $(t_{0.10})(S_Y)$ where S_Y is sample standard deviation of predicted Y, and

$$S_Y = S_{y \cdot x} \sqrt{1 + \frac{1}{n} + \frac{x^2}{\Sigma x^2}}$$

and $S_{y \cdot x}$ = sample standard deviation from prelogging regression, n = number of observations in prelogging regression, and $x = X - \bar{x}$ (Snedecor and Cochran 1956, p. 135-140). The hypothesis was that there is no difference between prelogging yield and postlogging yield. If a particular postlogging annual or seasonal yield exceeded the prediction limit, the hypothesis was rejected in favor of the alternate hypothesis that the yields are significantly greater than prelogging yields.

The significance of the difference between prelogging and postlogging peak flow data was determined by the principle of "extra sum of squares" (Draper and Smith 1966, p. 67-69). This principle tested the hypothesis that there is no difference between prelogging and postlogging regressions, i.e. $\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2$ where α is the intercept of the regression line, β is the slope, and subscripts 1 and 2 denote prelogging and postlogging periods, respectively (Harr et al. 1975).

Changes in Streamflow

ANNUAL YIELD

In the analysis of annual yields, the calibration period consists of water years 1964 and 1966-70. Because several stream gages were inoperative during part of the 1965 water year owing to bedload filling weir ponds, 1965 data have been excluded from the analysis of annual yield. In addition, data from 1971 have been omitted from the calibration and post-treatment periods because logging was underway during this year and watersheds were in neither an unlogged nor logged condition the entire year.

Prelogging correlation between annual streamflow at the control watershed and annual streamflow at each of the other watersheds used in this study was good. Prediction equations for the 5-year calibration period explain at least 98 percent of the variance in annual yield as indicated by r^2 values in table 4.

Logging operations significantly increased annual yield in all three logged watersheds (fig. 6). Because hydrologic changes caused by timber

Table 4--Summary of annual and seasonal streamflow relationships between logged watersheds CC-1, CC-2, and CC-3 (Y) and control watershed CC-4 (X)

Season	CC-1			CC-2			CC-3		
	$Y = \alpha + \beta X$			$Y = \alpha + \beta X$			$Y = \alpha + \beta X$		
	α	β	r^2	α	β	r^2	α	β	r^2
Full year	-1.93	1.00	0.982	-2.77	0.88	0.990	1.54	0.86	0.991
Fall	-.15	.86	.975	-.58	.89	.987	.04	.93	.997
Winter	22.5	.87	.978	.67	.80	.994	.70	.85	.995
Spring	1.24	.99	.904	-.33	.97	.972	.22	1.04	.980
Summer	.21	1.18	.694	-.16	.49	.771	.05	.98	.605

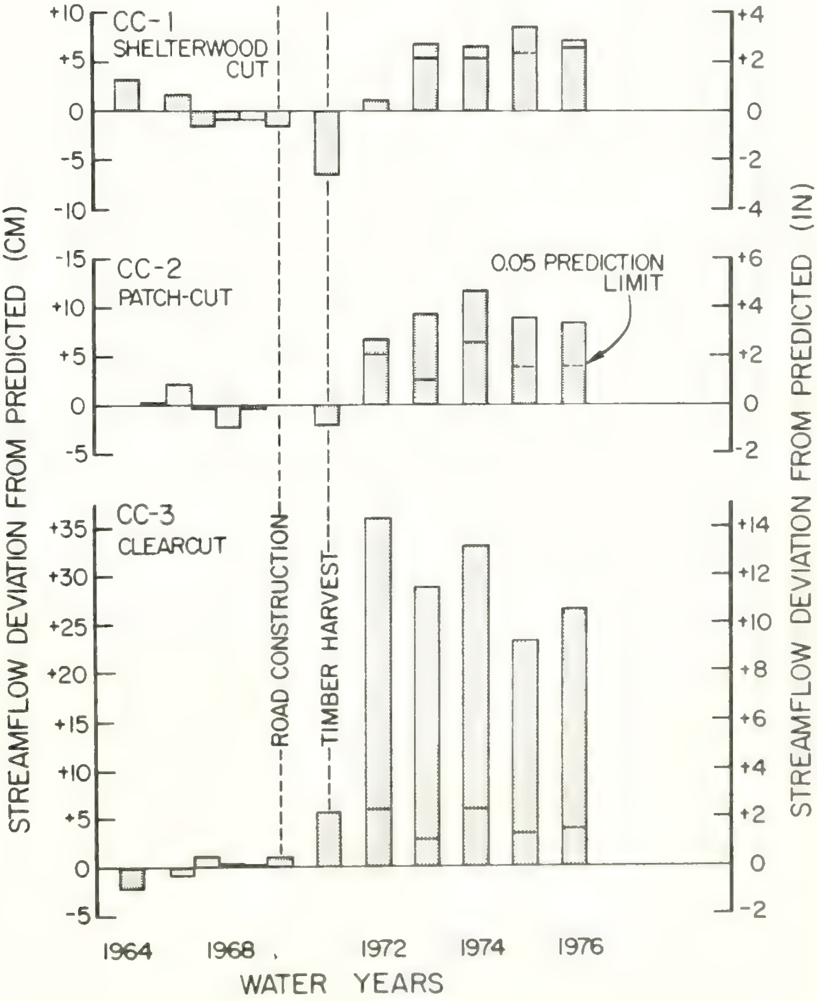


Figure 6.--Changes in annual streamflow after road construction and logging.

harvest cannot be separated from those caused by road building, the "treatment" evaluated here necessarily consists of timber cutting, soil disturbance associated with felling, yarding, and slash disposal, and the presence of roads. Increases in annual yield were largest at CC-3, the clearcut watershed. At CC-3 the first year increase was 36 cm (29 percent), and increases averaged about 29 cm (43 percent) during the first 5 years after logging. Increases averaged about 9.0 cm (14 percent) at CC-2 where small clearcuts and road rights-of-way occupy about 38 percent of the watershed. All post-treatment increases at CC-3 and CC-2 are statistically significant. At CC-1 where about 50 percent of total basal area of timber was harvested in a preparatory shelterwood cut and road rights-of-way occupy about 8 percent of the watershed, increases are significant for all years except 1972, the first year after logging. Increases at CC-1 have averaged 6 cm (8 percent).

Slight downward trends in increases of annual yield are apparent at CC-3 and CC-2 (fig. 6). Several additional years data, however, will be necessary to evaluate these apparent trends. At CC-1, the expected downward trend may be masked by the hydrologic effects of continuing deterioration of the residual forest in this watershed. By 1973 many trees, particularly those adjacent to skid roads and landings, were dead or dying, and additional trees died in subsequent years. Although the causes of death are not known, they appear to be related at least indirectly to damage the trees sustained during shelterwood cutting and to windthrow after logging.

SEASONAL STREAMFLOW

Seasonal streamflow data were analyzed to determine the time of year increases in yield occurred and to help identify the hydrologic processes most likely altered by timber harvesting activities. Monthly streamflow data were placed in four seasonal groups:

1. fall (October - November)
2. winter (December - March)
3. spring (April - June)
4. summer (July - September)

These periods roughly correspond to the major hydrologic seasons. During the fall period, soil water storage is being recharged; on the average, only about 6 cm (10 percent) of annual streamflow occurs in this period. As the winter storm season progresses, soil water storage becomes filled, transpiration decreases, and interception losses become an increasingly small percentage of gross precipitation of individual storms. Monthly streamflow becomes an increasingly large proportion of monthly precipitation. About 49 cm (79 percent) of annual streamflow occurs during the winter period. In spring, monthly precipitation is less, storms are smaller so that greater percentages of gross precipitation are lost to interception, and soil water content decreases as transpiration increases. On the average, spring accounts for only 6 cm (10 percent) of total annual streamflow. In summer, evapotranspiration is at its maximum, rainfall is infrequent, and streamflow generally decreases to annual minimums. Less than 1 cm (1 percent) of annual streamflow occurs during the summer period.

Results of seasonal yield analyses are shown in figure 7. Increases which exceed the 0.05 prediction limit occurred initially during the summer of 1971 when the watersheds were being logged. At CC-3, the totally clearcut watershed, 1971 summer flow was increased 2.2 cm (196 percent). Increases were more modest at the shelterwood cut and patch-cut watersheds. Largest

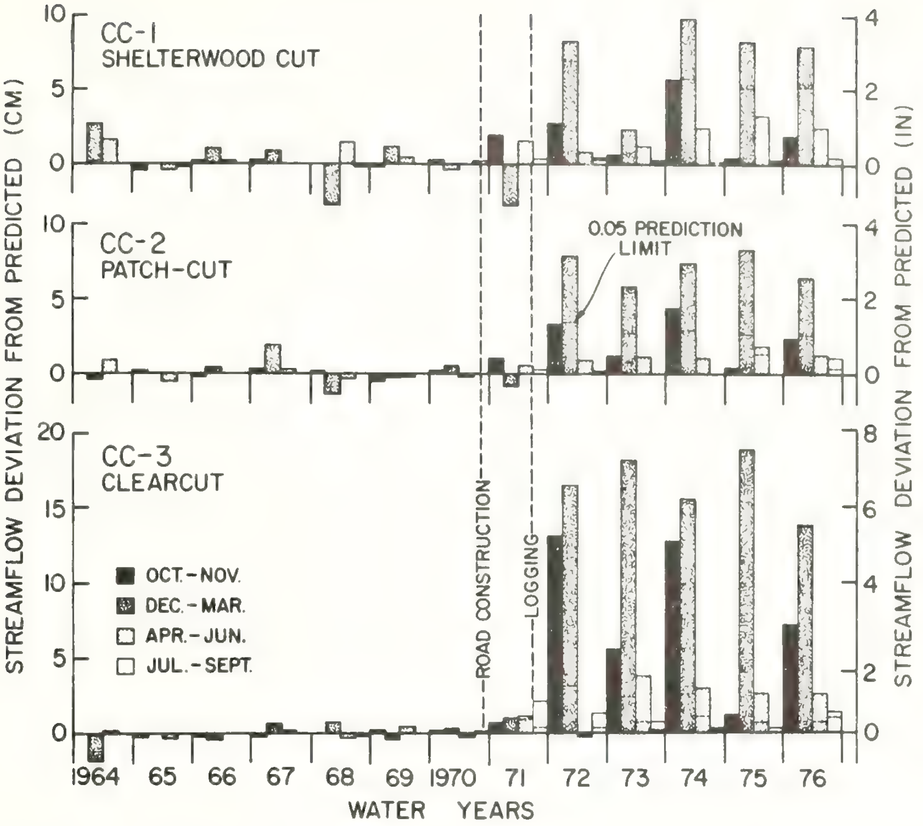


Figure 7.--Changes in seasonal streamflow after road construction and logging.

absolute increases in all postlogging years have occurred in the winter season at all watersheds. Of these, the winter increases at CC-3 have been the largest, averaging about 17 cm (33 percent) the first 5 postlogging years. Winter increases at CC-1 and CC-2 have averaged about 7 cm (14 percent). At all watersheds, fall has been the season of second largest increases, followed by spring and summer. Because of the small size of some increases at CC-1 and CC-2 and because of natural variation in seasonal flows, some increases at these two watersheds are not statistically significant (table 5). All increases at CC-3, however, are statistically significant at the 0.05 level.

Winter increases are large in absolute terms but in many years are smaller in relative terms than increases in other seasons. For example, the winter increase at CC-3 in 1975 was about 19 cm (fig. 7), much larger than the fall increase of 1.2 cm. The fall streamflow, however, was 166 percent greater than predicted flow, whereas winter streamflow was only 37 percent greater than predicted. Relative increases in all seasons are summarized in table 5.

INSTANTANEOUS PEAK FLOW

Instantaneous peak flows greater than 2.2 liters/sec·ha at CC-4, the control watershed, and corresponding peak flows at treated watersheds were tabulated by water year. Postlogging data were then compared with prelogging data to determine if peak flow relationships between treated and control watersheds had changed after logging.

Table 5--Percentage increases in observed seasonal flows after roadbuilding and logging relative to predicted seasonal flows in watersheds CC-1, CC-2, and CC-3

Water year	Fall			Winter			Spring			Summer		
	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3
1971	[1]25	[1]13	[1]8	[2]--	[2]--	[2]--	[3]17	[3]7	13	26	65	195
1972	34	39	135	11	11	23	9	11	[4]--	44	[3]20	134
1973	[3]55	150	400	16	34	100	[3]17	[3]20	59	37	[3]19	109
1974	34	24	63	16	13	26	[3]19	[3]9	24	[3]19	[3]5	43
1975	80	200	150	15	17	37	[3]37	23	30	42	40	46
1976	45	57	138	15	17	27	[3]29	[3]17	32	[3]21	126	70

[1] Increases occurred after roadbuilding.

[2] Winter of 1971 is included in the prelogging period.

[3] The increase is not significant at the 0.05 level of probability.

[4] Measured flow was less than predicted.

As evidenced by the relative positions of the prelogging and postlogging regression lines, size of peak flow was increased substantially after logging in CC-1 and CC-3, but only slightly in CC-2 (fig. 8). In addition, prelogging and postlogging regressions are significantly different only at CC-1 and CC-3 (table 6). For a peak flow of 10.9 liters/sec·ha at CC-4, a peak with a return period of about 9 years, size of corresponding peak flows at CC-1 and CC-3 were increased 48 percent and 35 percent, respectively. At CC-2, the increase was about 11 percent. Relative increases at other flow rates in each watershed may be obtained by comparing prelogging and postlogging regressions at those flow rates.

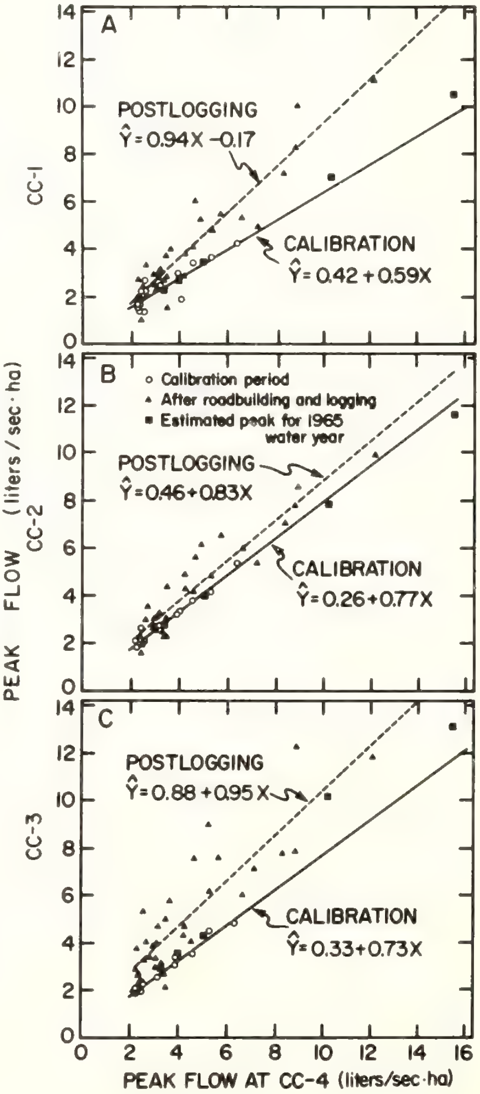


Figure 8.--Changes in peak flow relationships after road construction and logging in (A) *shelterwood cut,* (B) *patch-cut, and* (C) *clearcut watersheds.*

Table 6--Summary of changes in peak flow relationships between control and treated watersheds

atershed d period	Number of peaks > 2.2 liter/ sec·ha	Mean size of peak flow		$\hat{Y} = \alpha + \beta x$			Change at 10.9 liter/ sec·ha	F statistic
		Treated	Control	α	β	r^2		
		Liter/sec. ha					Percent	
1								
alibration	14	2.39	3.34	0.42	0.59	0.77	47	[1]5.86
ostlogging	32	4.00	4.44	-.17	.94	.89		
2								
alibration	14	2.82	3.34	.26	.77	.97	10	2.26
ostlogging	31	4.20	4.49	.46	.83	.89		
3								
alibration	14	2.77	3.34	.33	.73	.98	36	[1]9.92
ostlogging	33	5.02	4.38	.88	.95	.76		

[1] Calibration and postlogging regressions are significantly different at 0.05 vel of probability.

Discussion

WATER YIELD

Diminishing Increases

Although increases in annual and seasonal yields from forested watersheds in the South Umpqua region do occur, they are relatively small in comparison with both natural flows and total water needs for agricultural, domestic, and other users in the region. Such increases are as permanent as the changes in the forest hydrologic system that cause them. In most headwater basins, increases result primarily from reductions in evapotranspiration; both interception losses and soil moisture withdrawals by forest vegetation are drastically reduced so that more water is available for streamflow. But as reforestation proceeds, increases in streamflow will diminish and streamflow should eventually return to prelogging levels. In areas with compacted soil or where subsurface flow is intercepted by road cuts and ditches, increased overland flow may result in reduced soil moisture for evapotranspiration. In addition, these impacts on the hydrologic system may be more persistent than changes in evapotranspiration resulting from timber cutting. With only 5 years of postlogging streamflow data, we cannot accurately determine the rate at which increased annual yield will return to prelogging levels in southwestern Oregon. Studies elsewhere, however, suggest 30-35 years are necessary for yield increases to become negligible (Kovner 1956;

Swank and Helvey 1970). Predicting decline of yield increases is further complicated because we do not know how much of observed increase in yield has resulted from changes in evapotranspiration and how much from soil disturbance.

By using the following example, we can speculate that relatively large increases in water yield from small headwater basins will cause only very small increases in annual yield downstream. Similar examples have been used previously by Rothacher (1970) and Bethlahmy (1974). Consider a 100-km^2 forested watershed that yields 75 cm of water per year--a typical annual flow for this size watershed in the South Umpqua region. Assume that yield increases result entirely from reductions in evapotranspiration and that these increases diminish according to the hypothetical curve in figure 9 which conforms in general to results of other similar experiments (Swank and Helvey 1970). The equation for this curve is:

$$Q_t = Q_1 K^{t-1} \qquad (1)$$

where Q_t = increase in annual yield t years after clearcutting; Q_1 = 36 cm, the observed first year increase in yield at CC-3; and K = 0.9, a constant which represents the rate of change toward prelogging water yield. (When K = 0.9, equation (1) fits the data in fig. 9 reasonably well. Subsequent data will be necessary to determine the true value of K.) If the large, forested watershed is managed with a 100-year rotation and equal areas are clearcut each year, then 1 percent of the watershed will be in a freshly cut condition each year and, according to equation (1), will yield 36 cm more water than if it were uncut. Also, 1 percent of the large basin will yield, Q_2 = 32.4 cm more, 1 percent will yield Q_3 = 29.2 cm more, and so on.

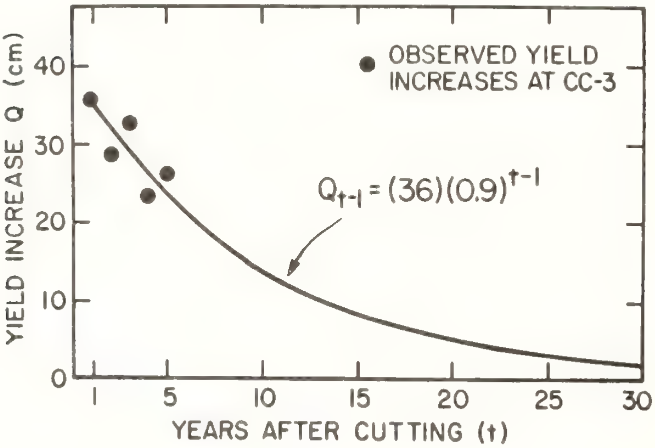


Figure 9.--Diminishing increases in annual yield.

If we assume that yield increases become negligible 30 years after timber cutting, then an area's total yield increase Q_t over 30 years is given by

$$Q_t = \int_1^{30} Q_1 K^{t-1} dt = 343 \text{ cm}. \qquad (2)$$

This amounts to an average of 11 cm each year for 30 years. In other words, 30 percent of the large watershed (30 years of a 100-year rotation) would yield 86 cm (75 cm + 11 cm), while 70 percent, having recovered hydrologically or never having been altered, would yield 75 cm. Annual yield for the large basin would be (0.30)(86) + (0.70)(75) = 78 cm, an increase of only 4 percent.

In many cases, increases in annual yield derived from forest cutting in headwater regions of large watersheds could not be detected at the mouth of the watershed. Excellent streamflow records have an error of ± 5 percent which would be about 4 cm for the large basin described above--about the same size of probable increases in annual yield for that basin. Thus, in many years, the increases in annual streamflow could be within the error associated with measurement of annual streamflow and therefore unmeasurable themselves.

A second portion of flow increases detected in the Coyote Creek watersheds resulted from surface soil disturbance and reduced soil permeability caused by roadbuilding, logging, and slash disposal and interception of subsurface water by road cuts and ditches. The hydrologic changes in a watershed caused by permanent roads are permanent. In addition, areas severely compacted by building temporary roads, tractor skidding of logs, and windrowing of slash may not recover fully for many years so that increased flow caused by reduced permeability may exist for a decade or longer. Compaction has persisted 40 and 55 years at two sites in western Oregon (Power 1974). Evaluation of flow increases caused only by soil disturbance, however, is impossible because such increases have occurred concurrently with those caused by reductions in evapotranspiration.

Timing of Increases

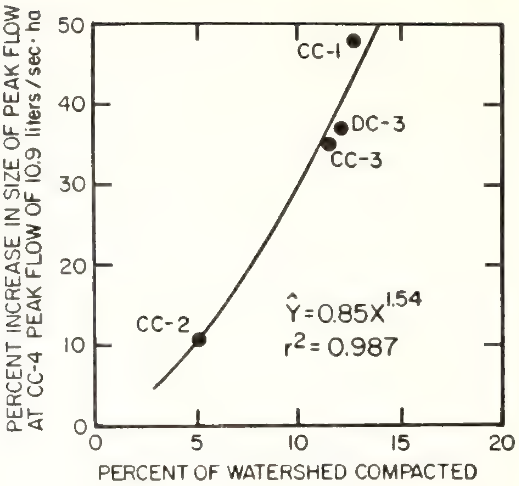
Another important factor that bears on the availability of streamflow increases for use in the South Umpqua watershed is the timing of these increases relative to the timing of water demand. Major increases have occurred during the December through March period when there is an abundance of streamflow but no agricultural demand for water. Conversely, when demand is high in summer, flow increases in that season are of little consequence compared to total demand for irrigation water. Therefore, without storage facilities, water yield increases appear to be of little economic benefit downstream. In addition, largest increases tend to occur during the wettest years when an increase in annual yield would be of least benefit to downstream users (Bethlahmy 1974).

PEAK FLOW

Relation to Soil Disturbance

Increases in size of peak flow appear to be related to amount of watershed area where soils were compacted (figs. 8 and 10). Data for the Deer Creek 3 watershed in the Oregon Coast Ranges also is included in figure 10. The relationship between peak flow and soil disturbance shown in figure 10, however, is oversimplified. This may be misleading because it ignores other factors such as proximity of compacted areas to streams, continuity of compacted areas such that overland flow can reach streams, interception of subsurface water by road cuts and ditches, and watershed soil and physiographic characteristics. In other words, all areas of compacted soil do not contribute toward increased runoff to the same degree. Nevertheless, percentage of compacted soil in a watershed appears to be a good indicator of increased size of peak flows.

Figure 10.--Apparent relationship between soil compaction and increase in size of peak flow. DC-3 is Deer Creek 3 of the Alsea Watershed Study (Harr et al. 1975).



Soil disturbance can affect size of peak flows in several ways, and the relative importance of each depends on the severity and the location of the disturbance. The most easily observed hydrologic effect of disturbance occurs where soil compaction has been sufficient to restrict infiltration and produce overland flow. If this surface water flows directly to a watercourse, for example, road drainage water entering a stream at a culvert where the road crosses a stream, the effect on streamflow is obvious. The size of the watershed's drainage network is increased, the runoff process becomes more efficient, and a greater amount of water arrives at the watershed outlet than would otherwise be the case. Even overland flow not directly reaching a watercourse, i.e., water flowing from severely compacted soil onto undisturbed soil where it infiltrates, should have an effect on storm runoff and size of peak flows. Although we do not know the exact nature of the movement of subsurface water in these experimental watersheds, it should be similar to that studied elsewhere in the western Cascade Range where soils are similar (Harr 1977). The infiltrating overland flow has the same effect as increased rate of rainfall. Unsaturated conductivities, which are dependent on soil water content, are higher than they would be without the addition of overland flow water. Thus, overland flow that infiltrates can increase runoff, but to a lesser degree than overland flow flowing directly into streams.

In CC-1, overland flow from many sections of roads has reached streams directly as has water from several skidroads and water from wet areas intersected by road cuts. In CC-3, overland flow from parts of both permanent and temporary roads in the upper part of the watershed has reached streams. These roads have also exposed and drained two wet areas. With the exception of some areas close to the stream in the lower part of CC-3, overland flow originating on soil compacted during tractor windrowing of slash has eventually infiltrated before reaching a stream. In CC-2, generally only water from some sections of road has reached streams directly; because of the location of the tractor-logged patch-cuts relative to streams, little overland flow from these areas appears to have entered streams.

Although they are also as difficult to detect downstream as are increases in annual yield described earlier (Rothacher 1970, Bethlahmy 1974), increases in peak flow caused by logging activities are of concern both locally and downstream. Overland flow and attendant surface erosion may increase sediment supply to streams, increased peak flows may erode streambanks and beds, and increased sediment may affect downstream aquatic resources.

Trends After Logging

Increases in size of peak flow must be examined in terms of their permanence as well as the size of peak flows that are increased. A double-mass analysis (Searcy and Hardison 1960) of peak flow data was used to detect trends in the peak flow relationships shown in figure 8. Cumulative measured peak flow (cumulations of all instantaneous peak flows, 2.2 liters/sec·ha) at each watershed was plotted over cumulative predicted peak flow at each watershed. An increase in the slope of a line fitted through the plotted points indicates increased size of peak flow at the logged watershed relative to size of peak flows during the calibration period.

Double-mass curves are shown in figure 11. The occurrence of major runoff events and the times of completion of road building and logging are also shown. At each of the three watersheds, the slope of the double-mass curve increased slightly after roadbuilding and considerably after logging. Five years after logging, there are no definite trends toward calibration peak flow relationships in any watershed.

Frequency Analysis

A peak flow frequency analysis was made to set the limits on the return period to which results of this study apply. A peak flow frequency relationship was obtained by fitting 1964-1976 peak flow data at CC-4 to a log-Pearson Type III distribution (U.S. Water Resources Council 1976) (fig. 12). Using this analysis, we estimate peak flows with return periods of 5, 10, and 25 years to be 8.2, 11.5, and 16.9 liters/sec·ha respectively. We emphasize that these are crude estimates because of the short-term record and because the peak flow of December 22, 1964, the largest of record, was estimated at the CC-4 stream gage by correlation with peak flow at the CC-2 gage, the only gage to function properly during that extreme runoff.

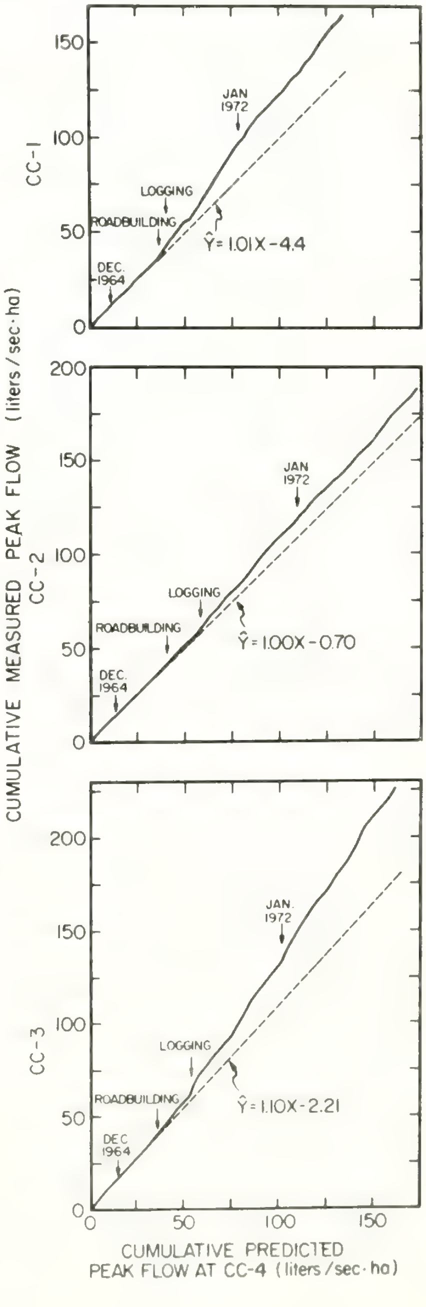


Figure 11.--Double-mass analysis of changes in peak flow after roadbuilding and logging, 1972-1976.

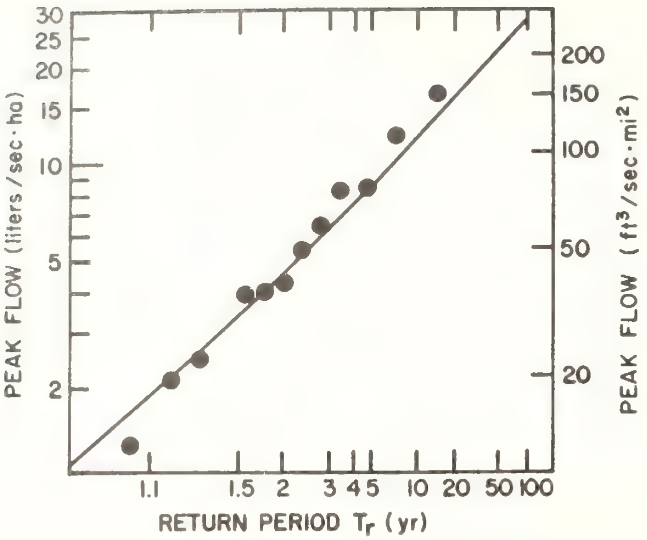


Figure 12--Log-Pearson Type III frequency curve for peak flows at CC-4, Coyote Creek Experimental Watersheds, 1964-1976.

During the calibration period of this study, size of peaks 2.2 liters/sec·ha averaged only 3.3 liters/sec·ha at CC-4, less than the mean annual peak flow of 4.4 liters/sec·ha estimated by the frequency analysis. (By definition, mean annual peak flow has a 50-percent chance of being equaled or exceeded in any 1 year or has a return period of about 2 years.) In the postlogging period, peak flows at CC-4 have averaged 4.4 liters/sec·ha. Of the 32 postlogging peaks, 11 have been larger than the mean annual peak flow estimated from the frequency analysis.

Because of the preponderance of small peaks in both prelogging and postlogging periods, extrapolation of results to large infrequent peak flows is tenuous. If estimated peak flows during water year 1965, which are plotted in figure 8, are included in the peak flow analyses, the position of the CC-1 and CC-3 calibration regression lines would be moved slightly upward causing the predicted increases in large peaks to be smaller than described earlier. For CC-2, the calibration regression would be lowered slightly and would cause the predicted increase in larger peak flows at this watershed to be greater than described earlier. We believe, however, that the estimated peaks of water year 1965 are not accurate enough to be included in the calibration data and that the best estimates of changes in larger peak flows are given by the difference in calibration and postlogging regressions as plotted in figure 8 and summarized in table 5.

Culvert Design

In headwater areas of National Forests of western Oregon, culverts for stream crossings are designed to accommodate flows of certain return periods. Changes in the size of peak flows after soil disturbance caused by logging and slash disposal could influence the success of these culverts.

If the peak flow frequency analysis for CC-4 (figure 12) is applied to the data in figure 8, size of peak flows would be increased, and return periods for given peak flows would be reduced substantially at CC-1 and CC-3. For example, a peak flow with an estimated return period of 35 years before logging could have a return period of about 15 years after extensive soil disturbance thus more than doubling the chance of occurrence in any given year. The size of a 35-year peak flow in an undisturbed watershed could be increased to the size of a 100-year peak flow in a disturbed but otherwise identical watershed.

Although the foregoing is only a rough estimate of changes in return period which could occur after soil disturbance, this estimate can be used in a simple risk analysis to further illustrate possible effects of soil disturbance on size of peak flow. The probability of p_n of a peak flow being equaled or exceeded in the next n years is:

$$p_n = 1 - \left[\frac{T_r - 1}{T_r}\right]^n \qquad (3)$$

where T_r is the return period of the peak flow in years (Linsley et al. 1958). According to equation (3), there is a 52-percent chance that a peak flow with a return period of 35 years will be equaled or exceeded in the first 25 years of culvert use. But if logging operations upstream cause soil disturbance similar to that observed in CC-1 and CC-3, the 35-year peak flow would have an 82-percent chance of being equaled or exceeded in the first 25 years of culvert use after logging. To have only a 52-percent chance of being equaled or exceeded after logging, the culvert would have to be designed to accommodate a peak flow with a return period of 100 years. In terms of culvert size, a 61-cm (30-in) diameter culvert, for example, would be required after soil disturbance to provide at least the same risk of exceedance provided by a 45.7-cm (18-in) diameter culvert before soil disturbance.

We emphasize that the foregoing example is based only on changes in runoff and does not take into account both natural and logging-caused debris. Such debris has been a common reason for failure of culverts which should have accommodated any increased size of peak flows caused by logging activities (Rothacher and Glazebrook 1968).

RELATION TO MASS EROSION

Changes in the forest hydrologic system responsible for changes in streamflow after timber harvest may also adversely affect certain types of mass erosion in southwestern Oregon. Much of the downslope movement of soil masses in creep and earthflow terrain occurs during the fall and winter when maximum soil water levels occur (Swanson and Swanston 1977). Reduced interception and transpiration after logging, by increasing the amount of water entering the soil and decreasing its rate of withdrawal from the soil, may cause higher soil water levels or result in longer periods of time soil water remains at a level conducive for acceleration of soil creep or earthflow. Prolonged periods of active creep or earthflow movement during a single rainy season or reactivation of dormant creep and earthflow terrain may be the result (Swanston and Swanson 1976).

Increases in size of peak flow can increase rates of mass erosion also by changing erosion processes in streams. By removing lateral support for soil masses upslope from stream channels, higher peak flows can cause bank slumping which supplies large volumes of sediment and organic debris to channels.

Together, increased soil water content and higher peak flows may help explain increases in bedload export from CC-3 after logging (Swanson and Swanston 1977).

Summary

1. By reducing evapotranspiration and increasing overland flow, three types of timber harvest increased annual water yield up to 36 cm. For 5 years after logging, yield increases averaged 29 cm (43 percent) at CC-3, the completely clearcut watershed; 9 cm (14 percent) at CC-2, where timber was harvested in 20 small clearcuts; and 6 cm (8 percent) at CC-1, where timber was shelterwood cut.

2. Largest absolute increases in yield occurred during the winter at all watersheds. Largest relative increases occurred in fall and summer.

3. Sizable regional increases in water yield do not appear to be a product of sustained yield forest management practiced by the U.S. Forest Service in southwestern Oregon. Yield increases are as permanent as the changes in the forest hydrologic system that cause them. Large yield increases in recently logged headwater basins appear to be overshadowed by normal water yield from uncut or reforested basins so that yield increases for a large parent watershed probably amount to only about 4-6 percent.

4. After logging, size of peak flow corresponding to a peak flow of 10.9 liters/sec·ha at CC-4 was increased about 48 percent at CC-1, 35 percent at CC-3, and 11 percent at CC-2.

5. Increases in size of peak flow appear to be related to amount of watershed area where soils were severely disturbed. Soil disturbance and interception of subsurface water by roadcuts and ditches may affect surface erosion, stream channel erosion in headwater areas, and peak flows used to select culvert sites.

Acknowledgments

We thank W. Scott Overton of Oregon State University for his statistical advice and Robert L. Beschta of Oregon State University, Richard J. Janda of the U.S. Geological Survey, and Gerald W. Swank and other National Forest hydrologists for reviewing this manuscript. We are indebted to Alfred B. Levno and Phyllis M. Frazer for streamflow data collection and reduction.

Literature Cited

Bethlahmy, Nedavia.
1974. Water supply as affected by micro- and macro-watershed management decisions on forest lands. Northwest Sci. 48(1):1-8.

Draper, N. R., and H. Smith.
1966. Applied regression analysis. p. 67-69. John Wiley and Sons, Inc., New York.

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Harr, R. D.
1977. Water flux in soil and subsoil on a steep forested slope. J. Hydrol. 33:37-58.

Harr, R. Dennis.
1976. Forest practices and streamflow in western Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-49, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Harr, R. Dennis, Warren C. Harper, James T. Krygier, and Frederic S. Hsieh.
1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water Resour. Res. 11(3):436-444.

Harris, D. D.
1973. Hydrologic changes after clear-cut logging in a small Oregon coastal watershed. J. Res. Geol. Surv. 1(4):487-491.

Hayes, G. L.
1959. Forest and forest-land problems of Southwestern Oregon. 54 p. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Hayes, G. L., and H. G. Herring.
1960. Some water problems and hydrologic characteristics of the Umpqua Basin. 22 p. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Hibbert, Alden R.
1967. Forest treatment effects on water yield. *In* W. E. Sopper and H. W. Lull (eds.). International Symp. on For. Hydrology, p. 527-543. Pergamon Press, New York.

Kays, M. Allan.
1970. Western Cascades volcanic series, South Umpqua Falls Region, Oregon. The Ore Bin 32(5):81-94.

Kovner, J. L.
1956. Evapotranspiration and water yields following forest cutting and natural regrowth. Soc. Am. Foresters Proc., p. 106-110.

Linsley, Ray K., Max A. Kohler, and Joseph L. H. Paulhus.
1958. Hydrology for engineers. 258 p. McGraw-Hill Book Co., Inc., New York.

Power, W. E.
1974. Effects and observations of soil compaction in the Salem district. United States Department of the Interior, Bur. Land Manage. Tech. Note T/N-256. 18 p.

Richlen, E. M.
1973. Soil survey of the South Umpqua area, Oregon. 60 p. USDA Soil Conserv. Serv., Washington, D.C.

Rothacher, Jack.
1970. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resour. Res. 6(2):653-658.

Rothacher, Jack.
1973. Does harvest in west slope Douglas-fir increase peak flow in small forest streams? USDA For. Serv. Res. Pap. PNW-163, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Rothacher, Jack, and Thomas B. Glazebrook.
1968. Flood damage in the National Forests of Region 6. 20 p. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Searcy, James K., and Clayton H. Hardison.
1960. Double-mass curves. United States Department of the Interior Geol. Surv. Water-Supply Pap. 1541-B. p. 31-66.

Snedecor, George W., and William G. Cochran.
1956. Statistical methods, 5th ed. 534 p. Iowa State Univ. Press, Ames, Iowa.

Swank, W. T., and J. D. Helvey.
1970. Reduction of streamflow increases following regrowth of clearcut hardwood forests. Symp. on the Results of Research on Representative and Experimental Basins, Wellington, New Zealand, December 1970. Int. Assoc. Sci. Hydrol. Publ. 96:347-359.

Swanson, Frederick J., and Douglas N. Swanston.
1977. Complex mass-movement terrains in the western Cascade Range, Oregon. *In* Donald R. Coates (ed.), Reviews in Engineering, Vol. III, p. 113-124. Geol. Soc. Am., Boulder, Colorado.

Swanston, Douglas N., and Frederick J. Swanson.
1976. Timber harvesting, mass erosion, and steepland forest geomorphology in the Pacific Northwest. *In* Donald R. Coates (ed.), Geomorphol. and Eng., p. 199-221. Dowden, Hutchinson, and Ross Inc., Stroudsburg, Pa.

U.S. Army Corps of Engineers.
1975. Post flood report January 1974 in the Portland District, Oregon and Washington. U.S. Army Corp. Eng., Portland, Oreg.

U.S. Water Resources Council.
1976. Guidelines for determining flood flow frequency. 26 p. Hydrol. Comm. Bull. 17, U.S. Water Resources Council, Washington, D.C.

Waananen, A. O., D. D. Harris, and R. C. Williams.
1971. Floods of December 1964 and January 1965 in the far western states. Part 1. Description. 265 p. United States Department of the Interior Geol. Surv. Water-Supply Pap. 1866-A.

GPO 987-771

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in
southwestern Oregon. USDA For. Serv. Res. Pap.
PNW-249, 22 p., illus. Pacific Northwest Forest
and Range Experiment Station, Portland, Oregon.

Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in
southwestern Oregon. USDA For. Serv. Res. Pap.
PNW-249, 22 p., illus. Pacific Northwest Forest
and Range Experiment Station, Portland, Oregon.

Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in
southwestern Oregon. USDA For. Serv. Res. Pap.
PNW-249, 22 p., illus. Pacific Northwest Forest
and Range Experiment Station, Portland, Oregon.

Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in
southwestern Oregon. USDA For. Serv. Res. Pap.
PNW-249, 22 p., illus. Pacific Northwest Forest
and Range Experiment Station, Portland, Oregon.

Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

78:PNW-250

CLEMSON UNIVERSITY LIBRARY
MAR 29 1979
SCI., TECH. & AGR. DIV.

GOVT. DOCUMENTS
DEPOSITORY ITEM

CLEMSON
LIBRARY

usda douglas-fir tussock moth • research & development program

Decay in tops killed by Douglas-fir Tussock Moth in the Blue Mountains

Paul E. Aho / Boyd E. Wickman / Lee Roe

Research Paper PNW-250 February, 1979

Pacific Northwest Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture

Contents

INTRODUCTION 1

METHODS 1
  Selection of Study Areas and Trees 1
  Tree Dissection and Measurement 5
  Isolation and Identification of Decay Fungi 6
  Statistical Methods 6

RESULTS AND DISCUSSION 7
  Decay in Relation to Age of Top-Kill 7
  Decay in Relation to Diameter at the Base of Dead Tops . 7
  Decay in Rélation to Secondary Insect Attack 9
  Fungi and Other Microorganisms Associated With Decay . . 11
  Estimating Defect Associated With Dead Tops 11

RECOMMENDATIONS 21

LITERATURE CITED 21

METRIC EQUIVALENTS

1 cubic inch = 16.387 064 cubic cm

1 inch = 2.54 cm

1 foot = 0.3048 m

1 cubic foot = 0.02832 m^3

1 acre = 0.4047 ha

Breast height = 4.5 feet = 137.2 cm

ACKNOWLEDGMENT

The work leading to this publication was funded in part by the USDA Douglas-fir Tussock Moth Expanded Research and Development Program.

DECAY IN TOPS KILLED BY DOUGLAS-FIR TUSSOCK MOTH IN THE BLUE MOUNTAINS

Reference Abstract

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

RESEARCH SUMMARY

Research Paper PNW-250

1979

Douglas-firs and grand firs which were top-killed during tussock moth infestations approximately 4, 10, and 28 years ago were examined for incidence and extent of stem decay. Only 18 Douglas-firs with killed tops were found. Of 14 Douglas-firs with dead tops attributed to the tussock moth, only one top was infected and decay loss was small.

Of 149 grand firs studied, 92 were considered to be top-killed as a result of defoliation by the tussock moth or associated attack by bark beetles, mainly *Scolytus ventralis*. Bark beetles were the main cause of top-kill not related to tussock moth damage. The same factors influenced incidence and extent of decay associated with top-kills caused by either tussock moth defoliation or other agents. They include diameter at the base of dead tops and presence of secondary insect attack. Severity of decay was not related to years since top-kill--most likely because salvage logging and bark beetle attacks removed the most defective trees from the oldest infestation areas. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes increased with increasing basal diameter of dead tops. The incidence of infection and amount of decay were lowest in tops killed by defoliation only. In all study areas, decay was most severe when both bark beetles and wood borers attacked dead tops.

Unidentified fungi caused 85 percent of all decay columns and 76 percent of the total cubic decay volume associated with tops killed by all causes. Imperfect fungi and bacteria or yeasts, possibly associated with beetle attacks, were mainly isolated from decay columns caused by unidentified hymenomycetous fungi. *Amylostereum chailletii*, *Fomitopsis pinicola*, *Echinodontium tinctorium*, *Pholiota* sp., and *Stereum sanguinolentum* were isolated from decays associated with killed tops.

Two methods are given for making defect deductions for grand firs with tops killed by the tussock moth or other agents. Defect percentages of gross merchantable Scribner board-foot and cubic-foot volumes and average decay extent below the base of dead tops are tabulated by age and basal diameter of dead tops. Statistical tests indicate that these estimating methods may result in low accuracy, thus they should be used only as general guidelines by timber cruisers in the Blue Mountains.

Introduction

During the period 1971-74, the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDonnough) extensively damaged timber on more than 800,000 acres in Oregon, Washington, and Idaho (Graham et al. 1975). Extensive top-killing of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and grand fir (*Abies grandis* (Dougl.) Lindl.) occurred on 292,000 acres of moderately damaged timber, and some top-kill was scattered through 419,000 acres of lightly damaged stands (Graham et al. 1975, Wickman 1978). Decay entering through killed tops may increase timber loss following tussock moth infestation. Forest managers need to know the progress of decay to plan utilization of trees damaged by defoliation. This information is presently unavailable for grand fir and Douglas-fir in the Blue Mountains of eastern Oregon and Washington.

Although "wetwood" was common (Wickman and Scharpf 1972), little deductible defect was associated with white fir (*Abies concolor* (Gord. & Glend.) Lindl.) in California 33 years after top-killed by the tussock moth. This information may not be applicable to tree species in the Blue Mountains, because decay varies widely between regions (Wagener and Davidson 1954). Johnson and Hadfield[1] examined Douglas-firs and grand firs top-killed by the tussock moth during an epidemic from 1963-65 in the Kings Mountain area, Burns Ranger District, Malheur National Forest, Oregon. Their sample was too small, however, to apply top-kill and associated decay information to forest management.

Our objectives were to assess the impact of decay entering grand fir and Douglas-fir through tops killed by the tussock moth or secondary beetle attack up to 3 years after the infestation in the Blue Mountains ended. This assessment of pathology included frequency of infection, extent of decay, identification of decay organisms, and development of equations for use in estimating the amount of decay associated with dead tops.

Methods

SELECTION OF STUDY AREAS AND TREES

Grand firs and Douglas-firs with dead tops evidenced by spike (fig. 1), bayonet (fig. 2), forked (fig. 3), or crooked (fig. 4) tops (Wickman and Scharpf 1972) were selected for study in three areas in the Blue Mountains known to have been severely attacked by the tussock moth in the past. Nine localities were sampled near Fox Prairie and Round Mountain, Umatilla National Forest. Sample trees were selected near plots which were installed to study damage caused during the 1972-74 tussock moth infestation (fig. 5).

---

[1] Johnson, David W., and James S. Hadfield. 1975. Defect in Douglas-fir and grand fir top-killed by the Douglas-fir tussock moth. USDA For. Serv., Region 6, Div. of State and Private Forestry. Mimeo, 10 p.

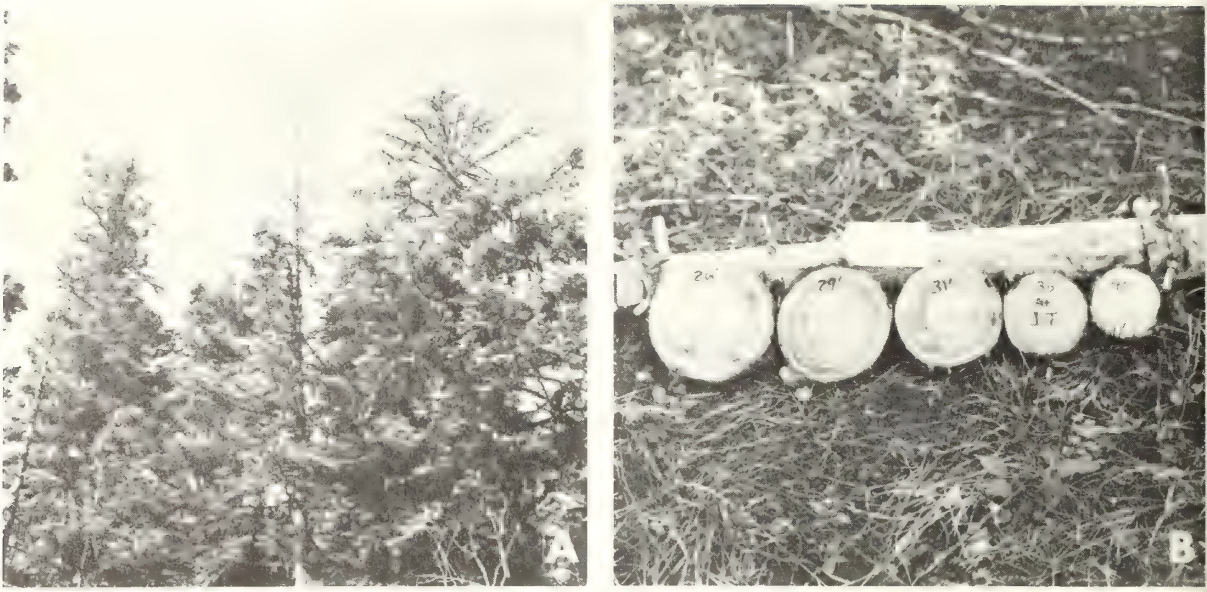


Figure 1.--A. Grand fir with 3-year-old dead (spike) top. B. Cross-sections at various heights in the same tree showing associated discoloration and decay.

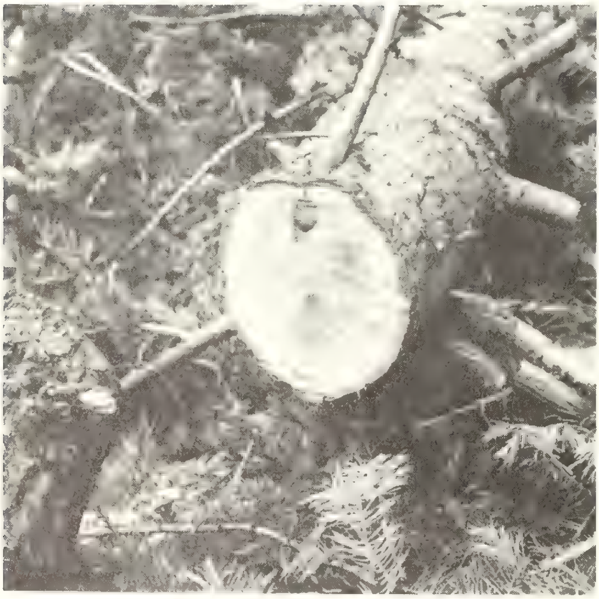


Figure 2.--Bayonet top on a grand fir resulting from death of original leader by tussock moth defoliation. Note that decay is confined to the dead top.

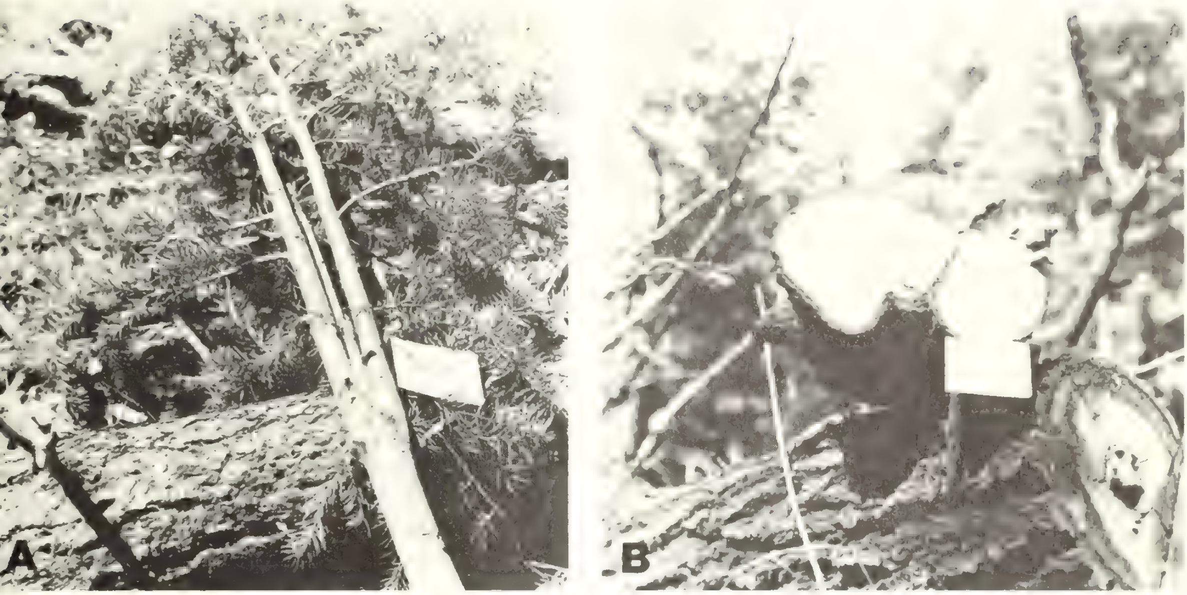
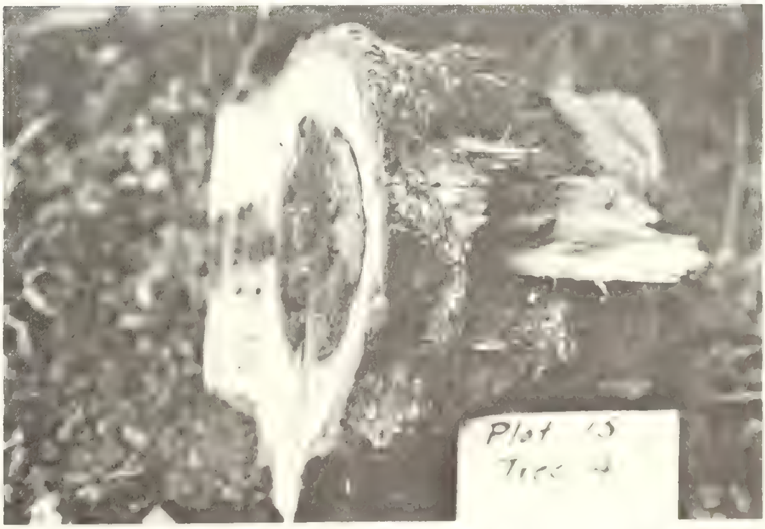


Figure 3.--A. Grand fir with a forked top caused by tussock moth defoliation 9 years ago. B. Cross-section at the base of a fork showing the buried original leader.

igure 4.--Cross-section at a crooked top resulting from death of the original leader due to tussock moth defoliation. The crook occurred when a lateral branch gained dominance, thus becoming the new top. Note the decay associated with the old broken leader.



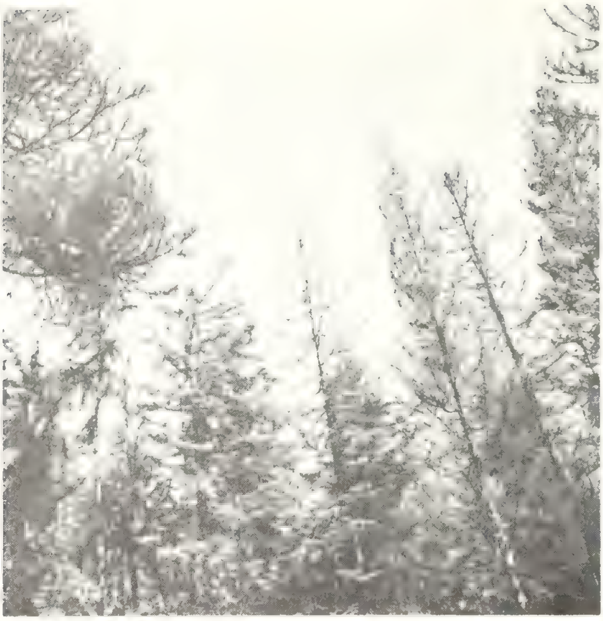


Figure 5.--Mortality and dead tops caused by Douglas-fir tussock moth defoliation during the 1972-74 infestation in the Blue Mountains.

Many trees with dead tops were available for study in these localities, therefore, trees were selected with a wide range of ages, diameters at breast height, and diameters at the base of dead tops.

Sampling took place at eleven localities near King Mountain, Malheur N.F.--the site of a 1963-65 tussock moth outbreak. Seven stands were sampled near Long Meadows Guard Station, Umatilla N.F. where a severe tussock moth infestation occurred from 1945 to 1947. Past salvage logging had removed many top-damaged trees in the two older infestation areas. Trees sampled in these areas were usually selected as encountered, unless we could determine by observation from the ground that a dead top was caused by recent bark beetle attacks.

Dead and deformed tops of sample trees were examined to establish the year in which the tops were killed (Wickman and Scharpf 1972, also see footnote 1) in order to attribute the probable cause of death to defoliation, secondary insect attack, or other causes. Since trees weakened by defoliation are susceptible to attack by beetles for several years (Wickman 1963), tops killed by secondary insects during, or within 3 years after the known infestation, were considered tussock moth damaged (fig. 6). An exception was in the oldest epidemic in the Long Meadows area, where trees with tops killed from 21-35 years ago (instead of 26-31 years) were considered damaged by tussock moth defoliation. The age range for this infestation was expanded because of the difficulty and probable errors in aging older dead tops. Some of the most recently killed tops probably originated during a spruce budworm outbreak which occurred in the early 1950's.

In the Fox Prairie and Round Mountain localities, the site of the most recent epidemic, 41 grand fir trees with dead tops associated with

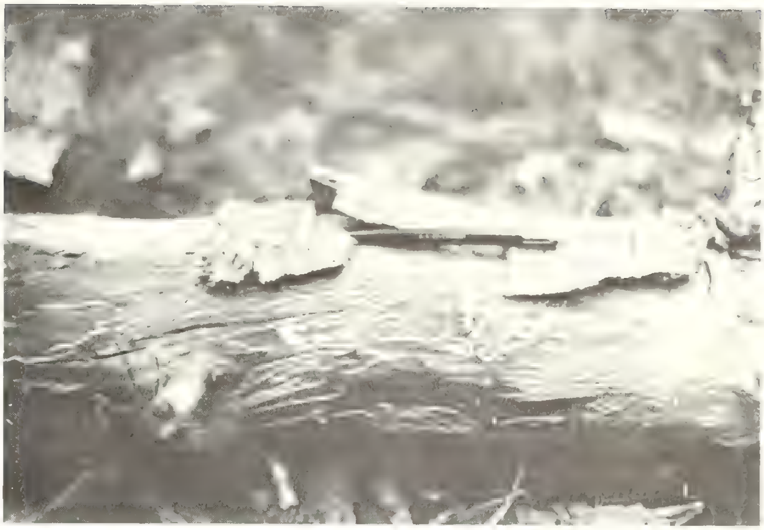


Figure 6.--Secondary bark beetle attack of grand fir weakened by tussock moth defoliation in the King Mountain infestation from 1963-65.

tussock moth defoliation were studied; 37 in the King Mountain area; and only 14 in the Long Meadows area (table 1). Trees found to be top-killed either before or more than 3 years after the infestation occurred in a given locality were studied for comparative purposes (table 1). Top-killing in these trees was considered to be caused by other (unknown) agents.

TREE DISSECTION AND MEASUREMENT

Selected trees with top-damage were felled at a stump height of 1 foot and dissected into 16-foot logs to a top d.i.b. of 4 inches for cubic

Table 1--*Numbers of grand fir study trees top-killed before, during, and after three Douglas-fir tussock moth infestations in the Blue Mountains*

Study locality	Date of tussock moth outbreak	Age of top-kill	Trees with tops killed: Before outbreak	Within 3 years after outbreak	More than 3 years after outbreak
		Years	- - - - - - -	-Number	- - - - - - -
Fox Prairie and Round Mountain	1972-74	2-5	3	41	0
King Mountain	1963-65	8-13	13	37	14
Long Meadows	1945-47	[1] 21-35	6	14	21

---

[1] To be considered as tops killed by tussock moths, the age should range from 26-31 years. The age range for this infestation was expanded, however, because of the difficulty of accurately aging older dead tops.

volume measurement. Board-foot volumes of trees 11-in d.b.h. and larger were measured to a top d.i.b. of 6 in. Disks were cut immediately above, at the base of, and below the damage. Ring counts were made at these points to determine when the top was killed. D.b.h., tree age at stump height, and location and description of decay indicators were noted for each tree. Logs were dissected further to measure the extent of decay associated with top-damage or other indicators.

We recorded the type of top-damage (i.e. spike top, broken top, fork, crook, etc.), and the height to and basal diameter of the killed top. Also recorded was the length of the dead top, the length and diameter of any new leaders, the year of top-kill, the extent of decay below and above the base of killed tops, and the presence or absence of secondary insect attack.

A program (PACUL) was developed at the Pacific Northwest Forest and Range Experiment Station to compute volumes of trees and decays. Cubic-foot volumes of logs and decay columns were calculated by the Smalian formula. No arbitrary cull rules were used in cubic-volume measurement. Gross board-foot volumes of logs in trees 11-inch d.b.h. and larger were computed by the Scribner log rule. Board-foot deductions for decay, shake, and frost cracks were made by the squared-defect method. In board-foot measurements, logs more than two-thirds defective were considered totally cull.

ISOLATION AND IDENTIFICATION OF DECAY FUNGI

Culture blocks, approximately 3 in^3 (7.6 cm^3) in size, were taken from disks cut at the base of and just below the dead top in most trees. These samples were always taken when discoloration or decay was present. Additional culture blocks were taken at various intervals from long decay columns. The blocks were placed in plastic bags and stored in an ice chest until taken to the laboratory.

In the laboratory, the blocks were split with a sterile chisel, and small wood chips were removed from freshly exposed discoloration or decay and placed on 2.5 percent malt agar slants in culture tubes. Inoculated tubes were incubated at room temperature.

The types (hymenomycetes, fungi imperfecti, and bacteria and yeasts) of microorganisms which had been isolated were noted. The hymenomycetous fungi were identified by Frances L. Lombard, Center for Mycology Research, Forest Products Laboratory, Madison, Wisconsin.

STATISTICAL METHODS

Regression and covariance analyses were used to test the relationships between cubic- and board-foot decay (as a percent of gross merchantable tree volumes) and top-kill age, base diameter of dead tops, presence of secondary insect attack, and to derive equations which can be used to predict the extent of defect associated with grand fir dead tops. The equations were used to tabulate defect as (1) percentages of gross merchantable tree cubic-foot and Scribner board-foot volumes, and (2) extent of decay (length of decay column) below the base of dead tops by age and basal diameter of killed tops.

Results and Discussion

We originally planned to study more Douglas-firs with tussock moth-killed tops than we did. It was, however, difficult to locate Douglas-firs with killed tops, at least in the areas where the oldest outbreaks had occurred. Furthermore, when Douglas-firs with killed tops were located, we found very little, if any, associated decay. Apparently, severely defoliated Douglas-firs were killed by bark beetles, other agents, or had been logged. Only 18 Douglas-firs with killed tops were felled and studied in the three areas of infestation. Only one (7 percent) of 14 trees top-killed by the tussock moth was infected with decay fungi, and less than 1 percent of the total cubic- or board-foot volume was lost to decay.

Basic data for 149 grand firs, from the three study areas with tops killed by the tussock moth and by other agents, are summarized in table 2. Ninety-two of the trees were considered to be damaged by the tussock moth. Decay associated with top-kill caused by other agents in each area of infestation was significantly ($P = <0.01$) greater than decay associated with tussock moth-killed tops, probably because dead tops killed by other agents were, on the average, older and had larger basal diameters. Decay volume not associated with killed tops was also significantly greater in grand firs top-killed by other agents than by the tussock moth (table 2).

DECAY IN RELATION TO AGE OF TOP-KILL

Decay associated with top-damaged trees, regardless of cause, was not significantly related to age of top-kill. We surmise that frequent salvage logging and repeated bark beetle attacks in the two older (King Mountain and Long Meadows) epidemic areas removed the more seriously damaged trees, thus, our sample mainly included the less damaged, less defective trees.

DECAY IN RELATION TO DIAMETER AT THE BASE OF DEAD TOPS

Cubic- and board-foot decay volumes associated with dead tops of grand firs from the three study areas combined, regardless of cause of the top-kill, increased significantly ($P = <0.05$) with increasing basal diameter of dead tops (table 3). The same relationship held for trees from each individual study area. Decay volumes were negligible in trees with tussock moth-killed tops with less than 2-in diameter at the base (fig. 7).

Wickman and Scharpf (1972) found no decay in white fir trees with killed tops less than 8-in diameter in the Mammoth Lakes area in California. Decay associated with tops killed by other agents was significantly greater ($P = <0.01$) than that associated with tops killed by the tussock moth (tables 2 and 3). Diameter at the base of dead tops can be useful to estimate the volume and extent of associated defect.

Table 2--*Basic data for grand firs top-killed by the Douglas-fir tussock moth and other agents from three localities in the Blue Mountains*

Cause of top-kill	Age range of top-kills (years)	Tree basis (No.)	Total top-kills infected (%)	Average				Cubic-foot volume associated with top-kill			Board-foot volume associated with top-kill			Decay not associated with top-kill			
				Tree		Top-kill								Cubic feet		Board feet	
				D.b.h. (in)	Age (yr)	Diameter at base (in)	Age (yr)	Gross	Decay	Decay (%)	Gross	Decay	Decay (%)	Total	Percent of gross	Total	Percent of gross
Tussock moth	2-35	92	75.0	14.2	100	4.7	9.6	3,684.0	176.6	4.8	18,977	1,053	5.5	191.7	5.2	1,435	7.6
Other agents	4-68	57	80.7	14.8	115	5.3	17.8	2,428.8	223.7	9.2	12,384	1,425	11.5	320.9	13.2	2,354	19.0
Total or average	2-68	149	77.2	14.4	106	5.0	12.7	6,112.8	400.3	6.5	31,361	2,478	7.9	512.6	8.4	3,789	12.1

Table 3--*Decay in relation to basal diameter of grand fir tops killed by the tussock moth and other agents in all study areas combined*

Diameter at base of dead top (in)	Cause of dead top	Tree basis (No.)	Average			Trees infected (%)	Cubic-foot volume		Board-foot volume		Decay extent below base of dead top (ft)
			Diameter at base of dead top (in)	Tree							
				D.b.h. (in)	Age (yr)		Gross	Decay (%)	Gross	Decay (%)	
0-2.0	Tussock moth	21	1.0	10.5	91	14.3	345.0	0.02	1,283	0.0	0.3
	Other	11	1.4	12.9	95	45.5	282.8	2.7	1,157	2.3	3.3
	All combined	32	1.1	11.3	92	25.0	627.8	1.2	2,440	1.1	1.3
2.1-4.0	Tussock moth	15	3.0	10.3	88	86.7	225.1	2.8	763	1.6	6.7
	Other	17	3.2	13.0	115	82.4	565.8	2.8	2,700	6.0	5.8
	All combined	32	3.1	11.7	102	84.4	790.9	2.8	3,463	5.1	6.2
4.1-6.0	Tussock moth	29	5.1	14.4	97	89.7	1,081.7	2.4	5,122	2.0	7.3
	Other	9	5.1	13.2	95	100.0	244.6	10.8	1,141	21.8	8.2
	All combined	38	5.1	14.1	96	92.1	1,326.3	3.9	6,263	5.6	7.5
6.1-8.0	Tussock moth	15	7.0	16.3	102	93.3	804.6	7.2	4,392	5.9	9.8
	Other	12	7.0	15.4	120	91.7	379.3	17.8	1,698	22.3	17.2
	All combined	27	7.0	15.9	110	92.6	1,183.9	10.6	6,090	10.5	13.1
8.1-10.0	Tussock moth	10	8.9	20.8	124	100.0	877.7	7.8	5,204	11.2	11.6
	Other	3	9.3	19.3	173	100.0	212.9	13.2	1,172	15.4	16.7
	All combined	13	9.0	20.4	135	100.0	1,090.6	8.9	6,376	12.0	12.8
10.1+	Tussock moth	2	12.8	26.6	215	100.0	349.9	5.2	2,213	4.5	9.0
	Other	5	14.0	26.5	174	80.0	743.4	10.5	4,516	9.4	16.4
	All combined	7	13.6	26.5	186	85.7	1,093.3	8.8	6,729	7.8	14.3

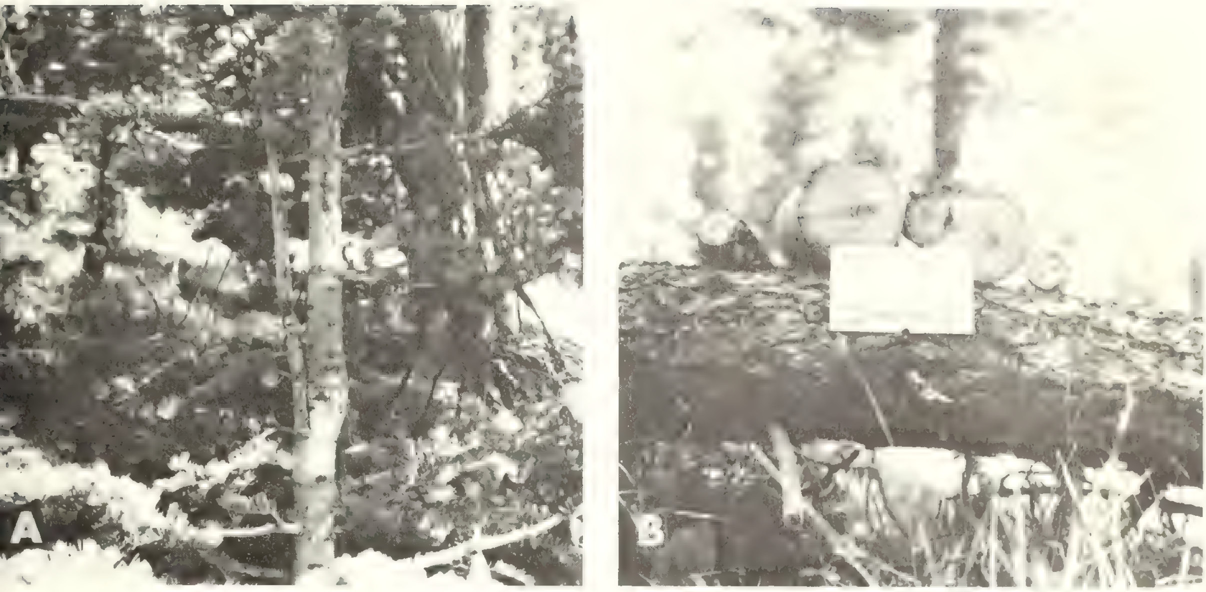


Figure 7.--A. Grand fir with tussock moth-killed top (9 years old) with a basal diameter less than 2 in. A lateral branch has become the new leader. B. The buried leader is discolored but not decayed. There is no discoloration or decay in the new leader.

DECAY IN RELATION TO SECONDARY INSECT ATTACK

Tops killed by tussock moth defoliation or other agents and also attacked by bark beetles and wood borers had high incidences of infection by fungi and decay was significantly ($P = <0.05$) more extensive than in tops killed only by defoliation (table 4). Apparently, these beetles are vectors of decay fungi or create favorable infection sites and conditions for decay. In all study areas, decay was most severe when both bark beetles and wood borers attacked dead tops (table 4). Bark beetles were associated with shallow infections of the outer sapwood and wood borer attack with infection and decay deep in the heartwood.

A high proportion (nearly 3/4) of trees with dead tops were attacked by bark beetles, either primarily or secondarily to tussock moth defoliation (table 5). Gallery patterns indicated that *Scolytus ventralis* Lec. was the bark beetle most frequently attacking killed tops. More study trees were attacked by bark beetles in the Fox Prairie-Round Mountain (77.3 percent of the total trees) and King Mountain (84.4 percent) areas, sites of the 2- to 5- and 8- to 13-year epidemics, respectively, than in the older infestation area at Long Meadows (56.1 percent). Wickman (1978) found that proportion of dead tops attacked by bark beetles increased with age of tussock moth infestation. Results in our study probably reflect the effects of salvage logging in the Long Meadows area. Severely damaged trees have been removed in logging operations which have frequently occurred in this area.

Table 4--*Decay associated with tops killed by the tussock moth and other agents in relation to secondary insect attack for grand firs from all study areas*

Secondary insect attack	Cause of dead top	No. of trees	Percent with decay	Average		Cubic-foot volume		Board-foot volume		Average decay extent below (ft)	Average diameter at base of dead top (in)
				Tree							
				D.b.h. (in)	Age (yr)	Gross	Decay (%)	Gross	Decay (%)		
None	Tussock moth	21	28.6	11.4	85	435.1	0.3	1,741	0.7	1	1.4
	Other	11	54.5	12.6	108	265.4	1.7	963	1.6	2	1.9
	Both combined	32	37.5	11.8	93	700.5	0.8	2,704	1.0	1	1.6
Bark beetles	Tussock moth	7	71.4	11.4	101	157.0	2.2	697	1.6	5	3.9
	Other	8	75.0	12.0	102	159.2	2.4	471	3.2	6	3.1
	Both combined	15	73.3	11.7	102	316.2	2.3	1,168	2.2	5	3.5
Wood borers	Tussock moth	3	66.7	8.9	118	34.8	5.2	68	0.0	4	3.2
	Other	3	66.7	8.4	113	26.9	26.0	-	-	14	4.1
	Both combined	6	66.7	8.7	115	61.7	14.3	68	0.0	9	3.6
Bark beetles and wood borers	Tussock moth	61	91.8	15.8	105	3,057.1	5.6	16,471	6.2	9	6.0
	Other	35	91.4	17.1	124	1,977.3	10.5	10,950	12.7	13	6.9
	Both combined	96	91.7	16.3	112	5,034.4	7.5	27,421	8.8	10	6.3

Bark beetle attack was not restricted to dead tops. More than 30 percent of all trees with dead tops were attacked by bark beetles both in the dead tops and in patches along the living boles (table 5). The extent of bark beetle attack below the base of dead tops increased with age of topkill regardless of cause (table 5).

FUNGI AND OTHER MICROORGANISMS ASSOCIATED WITH DECAY

Slightly more than 85 percent of all infections and more than 76 percent of the total cubic decay volume associated with dead tops were caused by unidentified fungi (table 6). Attempts to isolate decay fungi resulted mainly in isolation of imperfect fungi (61.9 percent of 357 attempts) and bacteria or yeasts (20.2 percent). Unidentified hymenomycetes (decay fungi) were isolated in 3.4 percent of the 357 isolation attempts (table 6). Apparently, imperfect fungi and bacteria, commonly associated with bark beetles and probably wood borers, are much faster growing on culture medium than decay fungi, excluding them. Wickman and Scharpf (1972) also had difficulty in isolating decay fungi from decay (incipient) associated with white fir dead tops. Imperfect fungi and bacteria were the most numerous microorganisms isolated from discolorations associated with dead tops of grand fir in the King Mountain area, Burns Ranger District (see footnote Hadfield 1975).

Amylostereum chailletii (Pers. ex Fr.) Boid., *Fomitopsis pinicola* (Swartz ex Fr.) Karst., *Echinodontium tinctorium* Ell. & Ev., *Pholiota* sp., and *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) were isolated from decays associated with dead tops (table 6). The most extensive decay columns were caused by *F. pinicola*.

The Indian paint fungus, *E. tinctorium*, decay columns may have resulted from reactivation of dormant infections of this fungus by death of the tree top (Etheridge et al. 1976).

Twenty-three decay columns were found associated with infection courts other than dead tops. Cause of decay was not identified in nearly 40 percent of these columns. Bacteria or yeasts and imperfect fungi were the only organisms isolated from them. The Indian paint fungus, *E. tinctorium*, caused slightly more than 30 percent of the decay columns, but nearly 90 percent of the total cubic decay volume. *Fomitopsis annosa* (Fr.) Karst. was isolated from six root and butt rot columns in the study trees.

Many additional isolations were attempted from trees that did not have decay or discolorations, other than wetwood, associated with dead tops. Most of these attempts did not yield organisms. Bacteria or yeasts and imperfect fungi were the only organisms isolated from wetwood (fig. 8) and clear wood. Wickman and Scharpf (1972) and Johnson and Hadfield (see footnote 1) had similar results when isolating from wetwood.

ESTIMATING DEFECT ASSOCIATED WITH DEAD TOPS

Defect factors are presented as a guide to timber cruisers and others interested in predicting losses from decay after tussock moth infestations have declined. They are presented as percentages of gross merchantable

Table 5--*Grand firs with dead tops infested with bark beetles in the killed portion only and in both the dead and living tree bole and extent of attack below the base of dead tops*

Study area	Cause of dead top	Total trees with dead tops	Trees attacked by bark beetles	Proportion of all trees attacked by bark beetles			Average extent of bark beetle attack below base of dead top
				Total	Restricted to dead top	Attack in dead top and living bole	
		- - - Number	- - - -	- - - - - - - -	Percent	- - - - - - - -	- - Feet - -
Fox Prairie and Round Mountain	Tussock moth	41	31	75.6	61.0	14.6	27.3
	Other	3	3	100.0	33.3	66.7	22.5
	All combined	44	34	77.3	59.1	18.2	26.1
King Mountain	Tussock moth	37	30	81.0	32.4	48.6	29.3
	Other	27	24	88.9	55.6	33.3	41.8
	All combined	64	54	84.4	42.2	42.2	33.4
Long Meadow Guard Station	Tussock moth	14	7	50.0	21.4	28.6	43.0
	Other	27	16	59.3	33.4	25.9	48.6
	All combined	41	23	56.1	29.3	26.8	46.5
All combined	Tussock moth	92	68	73.9	43.5	30.4	30.8
	Other	57	43	75.4	43.8	31.6	42.3
	All combined	149	111	74.5	43.6	30.9	35.3

Table 6--*Fungi and other micro-organisms from decays associated with top damage of grand fir*

Apparent cause of decay	Trees	Decay columns	Average decay volume		Decay volume		Results of cultural isolation attempts				
			cu ft	bd ft	cu ft	bd ft	Total isolation attempts	Hymeno-mycetes	Fungi imperfecti	Bacteria or yeasts	No growth
	Number	Percent of total			- Percent -		Number	- - - - - - Percent of total - - - - - -			
Unidentified	97	85.1	3.0	24	76.4	69.0	357	3.4	61.9	20.2	14.5
Amylostereum chailletii (Pers. ex Fr.) Boid.	5	4.4	1.5	5	1.9	0.8	23	56.5	30.4	4.3	8.8
Fomitopsis pinicola (Swartz ex Fr.) Karst.	4	3.5	15.8	140	16.4	23.3	16	50.0	37.5	12.5	0.0
Echinodontium tinctorium Ell. and Ev.	4	3.5	4.7	80	4.9	6.6	15	53.3	26.7	13.3	6.7
Pholiota sp.	3	2.6	0.5	4	0.4	0.2	8	87.5	12.5	0.0	0.0
Stereum sanguinolentum (Alb. and Schw. ex Fr.) Fr.	1	0.9	0.1	3	+	0.1	4	25.0	0.0	0.0	75.0
Total or average	114	100.0	3.4	30	100.0	100.0	425	11.6	56.5	18.2	13.7

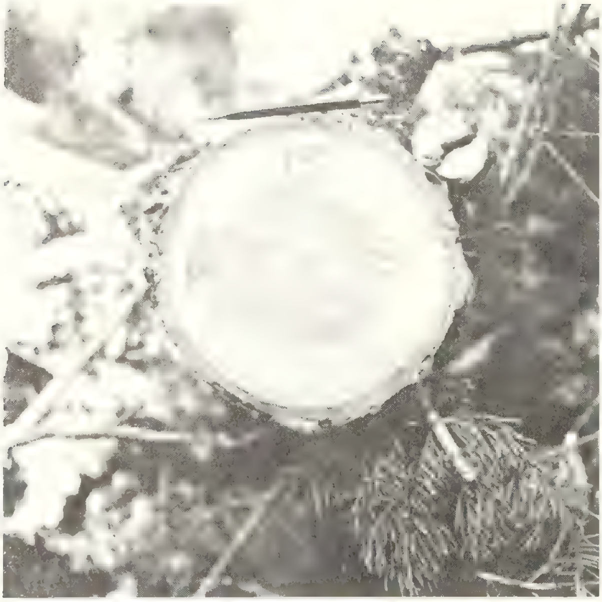


Figure 8.--Cross-section cut from a grand fir showing wetwood associated with a dead top and bark beetle attack.

tree cubic-foot and Scribner board-foot volumes (tables 7, 8, 9, 11) and average extent of decay below the base of dead tops (tables 10, 12). Defect percentages and average decay extents derived from regression analysis are tabulated by age and basal diameter of dead tops (tables 8-12). Equations used to derive the tables are presented in table footnotes. If the equatio are to be used in a computer program, consideration must be given to the fact that defect percentages or average decay extents for some combinations of age and basal diameter of dead tops can be less than zero. In these cases, provision should be made to set the percentages at zero.

Coefficients of determination (R^2) or the amount of variation in perce decay or decay extent that is explained by the variables in the equations are low (tables 7-12, footnote 1) thus values predicted by the equations wil often be of low accuracy and can be used as general guidelines only. Type of secondary insect attack as an independent variable in the equations woul raise coefficients of determination; however, in practice, this variable would not be useful to timber cruisers since it is usually necessary to fal and dissect trees to determine the type of secondary insect attack.

Tables 7-9 were developed from regression analysis of data for trees top-killed by the tussock moth or by secondary bark beetle attack. All trees, regardless of cause of top-kill, were used to develop tables 11-12. The first set of tables (7-9) or equations should probably be used to predict decay extent following known tussock moth infestations. The others (tables 10-12) can be used to estimate decay extent where tops are killed by any agent.

As an example, volume deductions for a grand fir tree top-killed (8 inches at the base of the dead top) by the tussock moth 10 years ago are 8.9 percent of gross merchantable cubic volume (table 7) and 8.6 percent of its Scribner volume (table 8). Average decay extent below the base of the dead top is 10.3 feet (table 9). Similar deductions can be found in tables 10-12 for trees with tops killed by other agents.

Table 7--*Defect in percent of gross merchantable cubic-foot volume for tussock moth top-damaged grand fir trees by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	Percent	- - - - - - - -	- - - - - - - -	- - - - - - - -
1	.000	.795	2.936	5.077	7.217	9.358	11.499	13.639
2	.000	.980	3.120	5.261	7.402	9.543	11.683	13.824
3	.094	1.164	3.305	5.446	7.586	9.727	11.868	14.009
4	.279	1.349	3.490	5.630	7.771	9.912	12.052	14.193
5	.463	1.534	3.674	5.815	7.956	10.096	12.237	14.378
6	.648	1.718	3.859	6.000	8.140	10.281	12.422	14.562
7	.832	1.903	4.044	6.184	8.325	10.466	12.606	14.747
8	1.017	2.087	4.228	6.369	8.510	10.650	12.791	14.932
9	1.202	2.272	4.413	6.553	8.694	10.835	12.976	15.116
10	1.386	2.457	4.597	6.738	8.879	11.019	13.160	15.301
15	2.309	3.380	5.520	7.661	9.802	11.943	14.083	16.224
20	3.232	4.303	6.444	8.584	10.725	12.866	15.006	17.147
25	4.156	5.226	7.367	9.507	11.648	13.789	15.929	18.070
30	5.079	6.149	8.290	10.430	12.571	14.712	16.852	18.993

---

[1] Derived from: Pc = -1.52967 + 0.184615 A + 1.07035 D;
where, Pc = percent of gross merchantable cubic-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.188$.

Table 8--*Defect in percent of gross merchantable Scribner board-foot volume for tussock moth top-damaged grand fir trees by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	Percent							
1	.000	.000	.536	3.020	5.504	7.988	10.472	12.956
2	.000	.000	.885	3.369	5.853	8.337	10.821	13.305
3	.000	.000	1.234	3.718	6.202	8.686	11.170	13.654
4	.000	.000	1.583	4.067	6.551	9.035	11.519	14.003
5	.000	.000	1.932	4.416	6.900	9.384	11.868	14.352
6	.000	.000	2.281	4.765	7.249	9.733	12.217	14.701
7	.000	.146	2.630	5.114	7.598	10.082	12.566	15.050
8	.000	.495	2.979	5.463	7.947	10.431	12.915	15.399
9	.000	.844	3.328	5.812	8.296	10.780	13.264	15.748
10	.000	1.193	3.677	6.161	8.645	11.129	13.613	16.097
15	1.696	2.938	5.422	7.906	10.390	12.874	15.358	17.842
20	3.441	4.683	7.167	9.651	12.135	14.619	17.103	19.587
25	5.186	6.428	8.912	11.396	13.880	16.364	18.848	21.332
30	6.931	8.173	10.657	13.141	15.625	18.109	20.593	23.077

---

[1] Derived from: $Pb = -4.78014 + 0.349001\ A + 1.24197\ D$;
where, Pb = percent of gross merchantable board-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.186$.

Table 9--*Decay extent below the base of grand fir dead tops caused by the tussock moth by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	Percent							
1	.737	1.876	4.154	6.432	8.709	10.987	13.265	15.543
2	.917	2.056	4.334	6.612	8.890	11.168	13.445	15.723
3	1.097	2.236	4.514	6.792	9.070	11.348	13.626	15.904
4	1.278	2.417	4.694	6.972	9.250	11.528	13.806	16.084
5	1.458	2.597	4.875	7.153	9.430	11.708	13.986	16.264
6	1.638	2.777	5.055	7.333	9.611	11.888	14.166	16.444
7	1.818	2.957	5.235	7.513	9.791	12.069	14.347	16.624
8	1.999	3.137	5.415	7.693	9.971	12.249	14.527	16.805
9	2.179	3.318	5.596	7.873	10.151	12.429	14.707	16.985
10	2.359	3.498	5.776	8.054	10.331	12.609	14.887	17.165
15	3.260	4.399	6.677	8.955	11.233	13.510	15.788	18.066
20	4.161	5.300	7.578	9.856	12.134	14.412	16.689	18.967
25	5.062	6.201	8.479	10.757	13.035	15.313	17.591	19.868
30	5.963	7.102	9.380	11.658	13.936	16.214	18.492	20.769

---

[1] Derived from: $Pd = -0.581668 + 0.180221\ A + 1.13893\ D$;
where, Pd = decay extent, in feet, below the dead-top base,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.250$.

Table 10--*Defect in percent of gross merchantable cubic-foot volume for top-damaged grand fir trees, regardless of cause, by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
					Percent			
1	1.490	2.616	4.870	7.123	9.376	11.629	13.882	16.135
2	1.573	2.700	4.953	7.206	9.459	11.712	13.965	16.218
3	1.657	2.783	5.036	7.289	9.542	11.796	14.049	16.302
4	1.740	2.867	5.120	7.373	9.626	11.879	14.132	16.385
5	1.824	2.950	5.203	7.456	9.709	11.962	14.215	16.468
6	1.907	3.034	5.287	7.540	9.793	12.046	14.299	16.552
7	1.991	3.117	5.370	7.623	9.876	12.129	14.382	16.635
8	2.074	3.201	5.454	7.707	9.960	12.213	14.466	16.719
9	2.157	3.284	5.537	7.790	10.043	12.296	14.549	16.802
10	2.241	3.367	5.620	7.874	10.127	12.380	14.633	16.886
15	2.658	3.785	6.038	8.291	10.544	12.797	15.050	17.303
20	3.075	4.202	6.455	8.708	10.961	13.214	15.467	17.720
25	3.493	4.619	6.872	9.125	11.378	13.631	15.884	18.137
30	3.910	5.036	7.289	9.542	11.795	14.048	16.301	18.555
35	4.327	5.454	7.707	9.960	12.213	14.466	16.719	18.972
40	4.744	5.871	8.124	10.377	12.630	14.883	17.136	19.389
45	5.161	6.288	8.541	10.794	13.047	15.300	17.553	19.806
50	5.579	6.705	8.958	11.211	13.464	15.717	17.970	20.223

---

[1] Derived from: $Pc = 0.280501 + 0.0834417\ A + 1.12652\ D$;

where, Pc = percent of gross merchantable cubic-foot volume that is cull,

A = dead-top age in years,

D = diameter at base of dead top in inches, and

$R^2 = 0.165$.

firs, regardless of cause, by dead-top age and diameter at the dead-top base[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- - - - - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - Percent	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
1	.907	2.016	4.235	6.453	8.672	10.891	13.109	15.328
2	1.123	2.233	4.451	6.670	8.889	11.107	13.326	15.545
3	1.340	2.449	4.668	6.887	9.105	11.324	13.542	15.761
4	1.556	2.666	4.884	7.103	9.322	11.540	13.759	15.978
5	1.773	2.882	5.101	7.320	9.538	11.757	13.976	16.194
6	1.990	3.099	5.318	7.536	9.755	11.973	14.192	16.411
7	2.206	3.315	5.534	7.753	9.971	12.190	14.409	16.627
8	2.423	3.532	5.751	7.969	10.188	12.407	14.625	16.844
9	2.639	3.748	5.967	8.186	10.404	12.623	14.842	17.060
10	2.856	3.965	6.184	8.402	10.621	12.840	15.058	17.277
15	3.938	5.048	7.266	9.485	11.704	13.922	16.141	18.360
20	5.021	6.130	8.349	10.568	12.786	15.005	17.224	19.442
25	6.104	7.213	9.432	11.650	13.869	16.088	18.306	20.525
30	7.187	8.296	10.514	12.733	14.952	17.170	19.389	21.608
35	8.269	9.379	11.597	13.816	16.034	18.253	20.472	22.690
40	9.352	10.461	12.680	14.899	17.117	19.336	21.554	23.773
45	10.435	11.544	13.763	15.981	18.200	20.418	22.637	24.856
50	11.517	12.627	14.845	17.064	19.283	21.501	23.720	25.938

---

[1] Derived from: $Pb = -0.418516 + 0.21654\ A + 1.10932\ D$;
where, Pb = percent gross merchantable board-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.116$.

Table 12--*Decay extent below the base of grand fir dead tops, regardless of cause, by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	Percent	- - - - - - - -	- - - - - - - -	- - - - - - - -
1	1.911	3.153	5.638	8.122	10.606	13.091	15.575	18.060
2	2.013	3.256	5.740	8.224	10.709	13.193	15.678	18.162
3	2.116	3.358	5.842	8.327	10.811	13.296	15.780	18.264
4	2.218	3.460	5.945	8.429	10.914	13.398	15.882	18.367
5	2.321	3.563	6.047	8.532	11.016	13.500	15.985	18.469
6	2.423	3.665	6.150	8.634	11.118	13.603	16.087	18.572
7	2.525	3.768	6.252	8.736	11.221	13.705	16.190	18.674
8	2.628	3.870	6.354	8.839	11.323	13.808	16.292	18.776
9	2.730	3.972	6.457	8.941	11.426	13.910	16.394	18.879
10	2.833	4.075	6.559	9.044	11.528	14.012	16.497	18.981
15	3.345	4.587	7.071	9.556	12.040	14.524	17.009	19.493
20	3.857	5.099	7.583	10.068	12.552	15.036	17.521	20.005
25	4.368	5.611	8.095	10.579	13.064	15.548	18.033	20.517
30	4.880	6.123	8.607	11.091	13.576	16.060	18.545	21.029
35	5.392	6.635	9.119	11.603	14.088	16.572	19.057	21.541
40	5.904	7.147	9.631	12.115	15.600	17.084	19.569	22.053
45	6.416	7.658	10.143	12.627	15.112	17.596	20.080	22.565
50	6.928	8.170	10.655	13.139	15.624	18.108	20.592	23.077

---

[1] Derived from: $Pd = 0.566989 + 0.102391\ A + 1.24220\ D$;
where, Pd = decay extent, in feet, below the dead-top base,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.251$.

Recommendations

This study suggests that in the Blue Mountains, grand firs with dead tops having basal diameters up to 2 inches will be practically free of associated decay, even after many years. Salvage or stand improvement operations should concentrate on removing trees with dead tops with large (>2") basal diameters to reduce future decay losses. Defect factors reported here will be useful as general guidelines to timber cruisers and markers in the Blue Mountains. They should not be relied upon in other areas where top-kill occurs because of possible variation in defect extent.

Secondary bark beetle and wood borer attack in dead tops greatly increases decay frequency and extent. Studies of population dynamics of beetles and borers in weakened trees and in damaged tops are needed. We need to know when attacks first take place, how long they last, the beetle populations, and the identity of bark beetles and wood borers.

We and others studying decay associated with dead tops have had difficulty isolating the hymenomycetous fungi causing decay. Apparently, faster growing, imperfect fungi, bacteria, and yeasts, probably associated with beetles, exclude the decay fungi from the culture media. Studies are needed to find: (1) antibiotics to suppress the growth of imperfect fungi and bacteria, and (2) isolation media which favors growth of decay fungi over their competitors.

Literature Cited

Etheridge, D. E., H. M. Craig, and S. H. Farris.
1976. Factors influencing infection and initiation of decay by the Indian paint fungus (*Echinodontium tinctorium*) in western hemlock. Can. J. For. Res. 6:299-318.

Graham, David A., Jack Mounts, and D. Almas.
1975. 1974 Cooperative Douglas-fir tussock moth control project, Oregon, Washington, and Idaho. USDA, For. Serv. Reg. 6, Pac. Northwest Reg., Portland, Oreg. 74 p.

Mounts, Jack.
1976. 1974 Douglas-fir tussock moth control project. J. of For. 74(2):82-86.

Wagener, Willis W., and Ross W. Davidson.
1954. Heart rots in living trees. Bot. Rev. 20(2):61-134.

Wickman, Boyd E.
1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA, For. Serv. Res. Pap. PSW-7, 15 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wickman, Boyd E.
1978. Tree mortality related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA, For. Serv. Res. Pap. PNW-233, 47 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E., and Robert F. Scharpf.
1972. Decay in white fir top-killed by Douglas-fir tussock moth. USDA, For. Serv. Res. Pap. PNW-133, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

GPO 987-595

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by Tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to race, color, sex or national origin.

RESEARCH PAPER PNW-25
MARCH 197

ITE INDEX AND
EIGHT GROWTH CURVES
FOR MANAGED,
EVEN-AGED STANDS OF DOUGLAS-FIR
EAST OF THE CASCADES
IN OREGON AND WASHINGTON

CLEMSON UNIVERSITY LIBRARY
JUN 14 1979
SCI., TECH. & AGR. DIV.

P. H. COCHRAN

GOVT
DEP
JU
CLEMSON
LIBRARY

usda · douglas-fir tussock moth · research & development program

FIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
DEPARTMENT OF AGRICULTURE FOREST SERVICE

The work leading to this publication was funded in part by the USDA Douglas-fir Tussock Moth Expanded Research and Development Program.

Site Index and Height Growth Curves for Douglas-fir in Managed, Even-Aged Stands East of the Cascades in Oregon and Washington

Reference Abstract

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziezii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Increment (height), site index, stem analysis, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon (eastern), Washington (eastern).

RESEARCH SUMMARY

Research Paper PNW-251

1979

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington were derived from stem analysis data from 22 sample plots in Oregon and 10 sample plots in Washington.

Height growth curves give estimates of expected heights at different ages for stands of known site index. Site index curves give estimates of site index of managed stands where only present breast height age and present total height are available.

The appropriate curves provide valid estimates of site index and potential height growth of the tallest trees for stands where height growth has not been retarded by high density or

related factors. They *do not* represent the average of existing stands.[1] The height growth curves are most appropriate for use in constructing yield tables for managed, even-aged stands of Douglas-fir or mixed conifers where Douglas-fir is a significant component.

These results stem from a study undertaken as part of the Douglas-fir Tussock Moth Expanded Research and Development Program. The purpose of the study was to determine potential production of stands susceptible to attack by tussock moth.

Curves are based on measurements of the tallest tree for its breast high age in a 1/5-acre plot.

---

[1] Summerfield, Edward R. Site index and height growth of Douglas-fir and ponderosa pine in eastern Washington. Washington State Department of Natural Resources Report 38 (in preparation for publication).

Contents

INTRODUCTION 1

METHODS. 1
    Data Collection. 1
    Curve Construction 2

RESULTS. 3

ESTIMATING SITE INDEX. 3

ESTIMATING THE COURSE OF HEIGHT GROWTH FOR STANDS OF A GIVEN SITE QUALITY . . . 6

APPLICATION. 8

LITERATURE CITED 8

APPENDIX 9
  Site Index Curve Construction. 9
  Height Growth Curve Construction 12

ntroduction

Over 9 million of the 20 mil- on acres of commercial forest nd in eastern Oregon and eastern shington is in mixed conifer rests.[2] Douglas-fir (*Pseudot- ga menziesii* (Mirb.) Franco) is primary component of many of ese forests occurring either in re stands or mixed primarily th white fir (*Abies concolor* ord. & Glend.) Lindl.), grand r (*Abies grandis* (Dougl.) ndl.), western larch (*Larix cidentalis* Nutt.), or ponderosa ne (*Pinus ponderosa* Laws.). e site index and height growth rves presented here are for uglas-fir in pure or mixed, en-aged, managed stands where latively low density, lack of p damage, and absence of vege- tive competition early in the fe of the stand permit full ight development.

A managed stand is being nipulated toward some goal, ually a "target" average diam- er and height within a set time ame. To attain these goals, e manager will often use some mbination of precommercial and mmercial thinnings and perhaps rly suppression of competing getation.

No stands exist that have been der such management throughout rotation. Therefore, I delib- rately chose stands for sampling at approximated densities be- eved desirable in managed stands, t merely the average of existing ands. Height growth from 4.5 et upward was apparently never duced by stand density, vege- tive competition, or top damage these stands.[3]

The height growth curves and site index curves presented here are two separate sets of curves constructed for two different objectives. Height growth curves are used in construction of yield tables for describing top height as a function of age and site index. Site index curves are used to determine an index to potential production from current height and age (Curtis et al. 1974).

Methods

Data Collection

Data came from thirty-two 1/5-acre circular plots (fig. 1) with these characteristics:

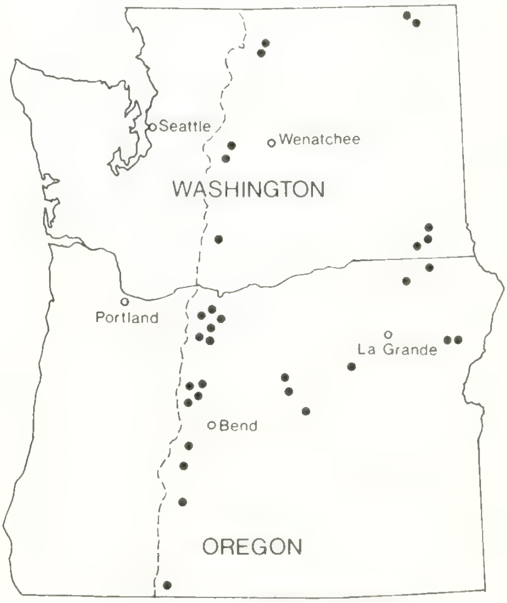


Figure 1.--Distribution of plots used in construction of curves for Douglas-fir.

1. The average breast high age was greater than 50 years. At ground line, the ages of the youngest trees were at least 80 percent of the ages of the oldest trees.

---

[2] 1 acre = 0.4047 hectare.

[3] 1 foot = 0.3048 meter.

2. The crown canopy was closed or nearly closed at the time of sampling. Stumps were absent; and mortality, if evident, was due to suppression and was less than 5 percent of the plot volume. Volume growth patterns for the plot determined from stem analysis of at least 12 sample trees across the range of diameter classes indicated that the highest periodic annual volume increment had occurred within the last 5 to 15 years. These factors indicate that there was no severe competition between trees in the past.

3. The dominant trees on the plot did not contain a group of narrow annual rings, which would indicate stress in the past.

4. Trees were not infected with disease, and no visible signs of insect defoliation were present.

5. Dominant trees did not exhibit crook in the bole, and internodal lengths did not indicate past top damage. Some plots were rejected after sampling because abrupt breaks in the height growth curves suggested substantial top damage 30 or more years earlier, even though this damage was not apparent at the time of selection.

6. Clumps of trees were not sampled. The plots were in homogeneous stands, and each plot had a buffer strip equivalent in width to tree height.

Diameter at breast height (d.b.h.) was measured for each tree on each plot, and 12 to 15 trees of each species on each plot were felled to determine past periodic annual increments for the plot. Included in this group were the three largest diameter trees. If taller trees existed on the plot, they were felled and their stem analysis data used for construction of the site in x and height growth curves but no in the volume determinations. Past volume and basal area grow for nonsample trees on the plot were predicted from their basal areas. Deliberately using the tallest tree in forming the predictive equations would have produced a biased overestimate of volume growth.

The three to five tallest Douglas-fir trees at the time o sampling were sectioned at a 1-foot stump, at 4.5 feet (bh), 10 feet, and then at 10-foot intervals up the stem after total height was measured. Sections at ground line were also taken from at least two of the largest diameter trees, two of the smallest diameter trees, and one tree with close to the mean diameter. Rings were counted for all sections and recorded for the appropriate height.

Curve Construction

An age of 50 years at breast height (4.5 feet) was chosen as the index age. For each plot, heights of the three to five tallest trees were plotted as a function of bh age[4] for each tre on a single sheet of graph paper The bh age for each tree was use as the independent variable in the initial plotting rather than average bh age because height growth from 0 to 4.5 feet seems to be greatly influenced by competition immediately adjacent to a seedling and perhaps by early animal damage. Thus, it is possible for dominant trees to e the same age at ground line ut to differ as much as 10 years t 4.5 feet. Use of an average h age for plotting heights esults in an underestimate of he height growth potential of he site under management. Shifts n the tree of maximum height for ts bh age among the sample trees ccurred on 50 percent of the lots. Freehand curves were rawn for each tree and the ighest points at each decadal ge interval were used in subequent construction of curves. ite index for each plot was efined as the tallest height t bh age 50. This procedure esembles that of Dahms (1963), xcept that Dahms used an average ge for the plot as the independnt variable in plotting the ourse of height growth for the allest trees.

---

[4] Because, on the average, internodes were cut in half, these height-over-age curves contain compensating errors but overall are not biased because age at 4.5 feet determined from ring counts was the independent variable.

From this point, the methodlogy outlined by Barrett (1978) s used; it includes the recent mprovements in curve construction ethods suggested by Curtis et al. 1974) and Dahms (1975). A brief utline is presented in the ppendix.

For the 10 sample plots in ashington, site indexes ranged rom 55 to 105.4. The 22 sample lots in Oregon had site indexes anging from 52.7 to 106.4. The verage site index was 84.47:

Number of plots	Site Index
4	50-59
4	60-69
3	70-79
3	80-89
13	90-99
5	100-110

esults

Detailed results are given in he appendix along with an outline of the methods of curve construction. Some understanding of curve construction leads to an appreciation of how they should be used so the appendix is recommended reading even for the occasional user.

Estimating Site Index

Site index curves are used to indicate the potential productivity of land. The curves here give the estimated height of the tallest tree when the breast high age of that tree is 50 years. Many of the same plot qualifications used in this study are applicable in selecting plots for measuring site index. The following steps and procedures are recommended for estimating the site index of a managed stand.

1. Select suitable plots with the following characteristics:

   (a) Even-aged at the ground line (practically, there are no older remanents from earlier stands and the present stand is one storied).

   (b) No visible signs of disease or insect attack to reduce height growth.

   (c) No narrow ring groups to indicate suppression.

   (d) Consistent internodal lengths on taller trees.

   (e) No remnant understory vegetation or suppression mortality to indicate competition early in the life of a stand.

2. Establish boundaries of a 1/5-acre plot with a prespecified shape.

3. Measure the height of the three to five tallest trees on the plot.

4. Extract increment cores from these trees to determine their breast-high age.

5. Using the breast-high age and total height for each tree, determine a site index value for each tree by one or more of the following alternatives.

(a) Use figure 2 for rough field estimates.

(b) Obtain a more precise estimate by using the appropriate a and b values in table 1 to solve the equation,

Site index - 4.5 feet =
a + b (height - 4.5 feet)

(c) For those wishing to program the estimating procedure in a calculator, the appropriate equation in the appendix can be used.

6. Record as the site index value for the plot, the highest of the three to five values determined.

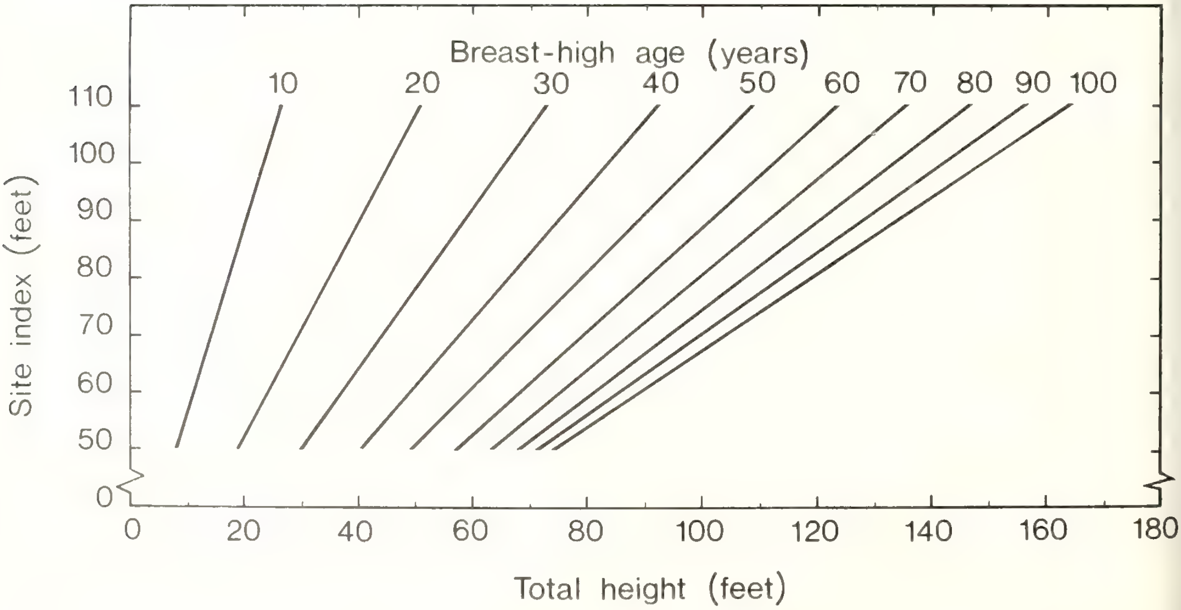


Figure 2.--Site index curves for manage, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest.

Table 1--Values for a and b by years for the family of regressions[1] for estimating site index for Douglas-fir east of the Cascades in the Pacific Northwest

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	32.217	3.235	30.319	2.936	28.679	2.778	27.069	2.602	25.550	2.451	24.113	2.319	22.751	2.204	21.457	2.103	20.229	2.012	19.056	1.931
20	17.940	1.853	16.875	1.792	15.585	1.731	14.886	1.676	13.958	1.625	13.069	1.579	12.219	1.535	11.406	1.495	10.627	1.458	9.881	1.423
30	9.168	1.390	8.484	1.359	7.830	1.331	7.204	1.304	6.605	1.278	6.032	1.254	5.483	1.231	4.959	1.209	4.458	1.188	3.979	1.168
40	3.522	1.150	3.085	1.132	2.760	1.114	2.274	1.098	1.896	1.082	1.537	1.067	1.196	1.053	.872	1.039	.565	1.025	.274	1.012
50	0	1	-.260	.988	-.505	.976	-.735	.965	-.951	.954	-1.153	.944	-1.342	.934	-1.518	.924	-1.691	.914	-1.832	.905
60	-1.971	.896	-2.098	.887	-2.214	.879	-2.319	.870	-2.413	.862	-2.496	.854	-2.569	.847	-2.632	.839	-2.685	.835	-2.729	.825
70	-2.764	.818	-2.789	.811	-2.806	.804	-2.814	.798	-2.814	.791	-2.805	.785	-2.789	.779	-2.764	.773	-2.732	.767	-2.693	.761
80	-2.646	.756	-2.593	.750	-2.532	.745	-2.465	.740	-2.391	.734	-2.311	.729	-2.224	.724	-2.132	.719	-2.033	.714	-1.938	.709
90	-1.818	.705	-1.703	.700	-1.582	.695	-1.455	.691	-1.324	.687	-1.187	.682	-1.046	-.961	-.900	.674	-.749	.669	-.594	.665
100	-.434	.661																		

---

[1] To estimate site index, measure height of the 3 tallest trees per 1/5-acre plot. Determine breast-high age for each of these trees. Select appropriate a and b values above. Substitute values in the equation, Site index - 4.5 feet = a + b (height - 4.5 feet). For example, for a tree 53 years old at breast height and 60 feet in total height, solve the equation, SI - 4.5 = -0.735 + 0.965 (60 - 4.5), for a site index of 57.3. Determine the site index for each of the 3 trees. The highest site index determined is the site index for the 1/5-acre plot.

Estimating the Course of Height Growth for Stands of a Given Site Quality

Height growth curves define the average pattern of height development for the tallest trees in stands of a given site quality. They are appropriately used for construction of yield tables but do not provide optimum estimates of site index from measured height and age in an existing stand (Curtis et al. 1974).

Three alternatives exist for estimating the anticipated heig of the tallest trees of a stand on land of known site index:

1. Rough field estimates through use of figure 3.

2. A more precise estimate using a_1 and b_1 values in table in the equation,

$$\text{Height} - 4.5 \text{ feet} = a_1 + b_1 \text{ (site index} - 4.5 \text{ feet)}.$$

3. An estimating procedure programed in a calculator using the equation shown in the appen

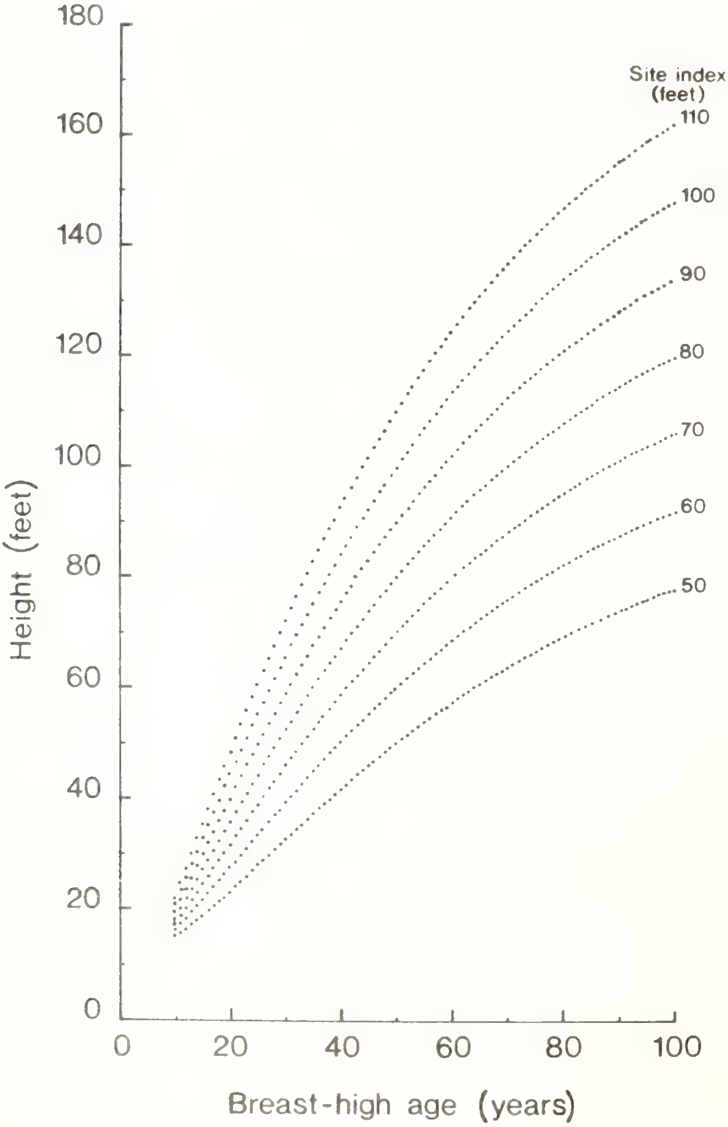


Figure 3.--Height growth curves for the tallest trees in manag even-aged stands of Douglas-f east of the Cascades in the Pacific Northwest.

Table 2--Values for a and b by years for the family of regressions[1] for estimating height of the tallest trees in a newly established stand of Douglas-fir east of the Cascades where site index and age are known

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	5.573	0.116	4.407	0.149	3.924	0.182	3.216	0.214	2.575	0.245	1.997	0.276	1.475	0.306	1.006	0.335	0.586	0.364	0.209	0.392
20	-.125	.419	[illegible]	.446	-.683	.472	-.911	.497	-1.108	.522	-1.127	.546	-1.418	.570	-1.534	.593	-1.627	.615	-1.698	.637
30	-1.749	.655	-1.781	.680	-1.795	.700	-1.192	.720	-1.773	.740	-1.740	.759	-1.692	.778	-1.632	.796	-1.560	.814	-1.477	.832
40	-1.383	.849	-1.279	.866	-1.166	.882	-1.045	.898	-.915	.913	-.778	.929	-.634	.944	-.484	.958	-.328	.972	-1.166	.986
50	0	1.000	.172	1.013	.348	1.026	.578	1.039	.711	1.051	.898	1.064	1.087	1.075	1.279	1.087	1.474	1.098	1.670	1.110
60	1.869	1.120	2.069	1.131	2.270	1.141	2.473	1.151	2.676	1.161	2.881	1.171	3.085	1.181	3.290	1.190	3.495	1.199	3.701	1.208
70	3.906	1.216	4.110	1.225	4.315	1.233	4.518	1.241	4.721	1.249	4.923	1.257	5.124	1.264	5.324	1.272	5.523	1.279	5.720	1.286
80	5.916	1.293	6.110	1.300	6.303	1.306	6.494	1.313	6.684	1.319	6.871	1.325	7.057	1.331	7.241	1.337	7.422	1.343	7.601	1.349
90	7.779	1.354	7.954	1.359	8.126	1.365	8.297	1.370	8.465	1.375	8.630	1.380	8.793	1.385	8.954	1.389	9.112	1.394	9.267	1.398
100	9.420	1.403																		

[1] Height at a future date of the tallest portion of a young stand may be estimated on land of known site index by selecting a and b values for the appropriate breast-high age. Substitute a_1 and b_1 values in the equation, Height - 4.5 feet = $a_1 + b_1$ (site index - 4.5 feet), for the particular breast-high age wanted. For example, for the height of the tallest tree in the stand at breast-high age 85 on land with a known site index of 100, solve the equation, HT - 4.5 - 6.871 + 1.325 (100 - 4.5), for a total height of 137.9 feet.

Application

In this study, site index is a number representing the height of the tallest tree for its breast-high age of 50 years on a 1/5-acre plot. Since site has been found to be closely correlated with volume (Spurr 1952), site index (as discussed here) will later be used in a yield study to categorize volume productivity potentials of managed stands of Douglas-fir east of the Cascades. Height objectively reflects site where undamaged stands are not overstocked. Stands managed for maximum production of usable wood, in contrast to natural stands, probably will not be overstocked to the point of substantially reducing height growth. Therefore, use of these curves should be restricted to even-aged stands where height growth competition between trees has been held to a minimum.

Typical examples of when the curves should not be used are:

1. Precommercially thinned stands showing a tight core of rings.

2. Commercially thinned stands with numerous stumps indicating a high initial density.

3. Plantations with large numbers of trees, thinned long after severe competition between trees occurred.

4. Stands that have been subjected to Douglas-fir tussock moth, spruce budworm, or other insect attacks that resulted in loss of top growth.

Only a limited amount of land is now under intensive management and fits the constraints of these curves. Greatest use will probably be in forecasting future stand performance in simulation models. Stand projections shou assign appropriate lesser heigh to other than the tallest trees in the stand. This problem of height assignment is currently being investigated.

A partial judgment of the reliability of the curves can be made by the r^2 values and the standard errors of the estimates shown in the appendix Equation fit can be judged from figures 8 and 9 in the appendix

Literature Cited

Barrett, James W.
1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Curtis, Robert O., Donald J. Demars, and Francis R. Herman.
1974. Which dependent variable in site index-height-age regressions? For. Sci. 20(1):74-87.

Dahms, Walter G.
1963. Correction for a possible bia in developing site index curves from sectioned tree data. J. For. 61(1):25-27.

Dahms, Walter G.
1975. Gross yield of central Oregon lodgepole pine. *In* Management of lodgepole pine ecosystems symposiu proceedings, p. 208-232, illus. David M. Baumgartner, ed. Wash. State Univ. Coop. Ext. Serv., Pullman.

Snedecor, George W., and William G. Cochran.
1967. Statistical methods. 6th ed. 593 p., illus. Iowa State Univ. Press, Ames.

Spurr, Stephen H.
1952. Forest Inventory. 476 p. Ronald Press Co., New York.

Appendix

For both site index and height growth curves, a curve of average height for the samples as a function of age at 4.5 feet is constructed. This height curve is then adjusted to the desired site index, using the linear relationship existing between height and site index at any age, with appropriate estimates of slope and intercept. The curves are different because slope and intercept values of the equations

$$\text{SI} - 4.5 \text{ feet} = a + b\,(\text{HT} - 4.5 \text{ feet}) \text{ and}$$

$$\text{HT} - 4.5 \text{ feet} = a_1 + b_1\,(\text{SI} - 4.5 \text{ feet})$$

are different for all ages except the index age (50 years for these curves).

SITE INDEX CURVE CONSTRUCTION

1. For the site index curves, the tallest heights (HT) at each decade were read from the freehand curves and related to the site index (SI) for each plot by the equation,

$$\text{SI} - 4.5 \text{ feet} = a + b\,(\text{HT} - 4.5 \text{ feet}). \qquad (2)$$

The following estimates were obtained:

Breast-high age (years)	a	b	r^2	Standard error of the estimate	Number of observations
10	32.2881	3.2310	0.3803	13.09	32
20	17.2388	1.8723	.7681	8.01	32
30	9.3532	1.3814	.9096	5.00	32
40	4.3867	1.1326	.9713	2.82	32
50	0	1	1	0	32
60	-1.7380	.8978	.9831	2.17	30
70	-1.1413	.8042	.9519	3.73	28
80	1.6845	.7048	.9498	3.98	18
90	-3.0283	.7101	.9489	3.96	10
100	-2.6900	.6767	.9399	4.03	10

The 10 sample plots with a bh age of 90 or more years have site indexes of 54.3, 55, 65.2, 69, 69.2, 81.8, 91, 91.6, 95, and 97.4 feet.

2. The above decadal estimates of b were smoothed over age (fig. 4) by the equation (forced though a b value of 1 at a breast-high age of 50 years),

$$\hat{b} = 0.52032 - 0.0013194 \text{ age} + 27.2823/\text{age};$$

where age here and in the equations to follow is breast high age. The standard error[5] and R^2 values for this equation are 0.0213 and 0.9994, respectively.

---

[5] Standard error in this paper used with nonlinear equations is equal to $(\Sigma\,(y - \hat{y})^2/(n - k))0.5$; where y and $\hat{y}$ are actual and predicted values, n is the number of points used to fit the curve, and k is the number of parameters that have been estimated in fitting the regression (Snedecor and Cochran 1967, p. 385).

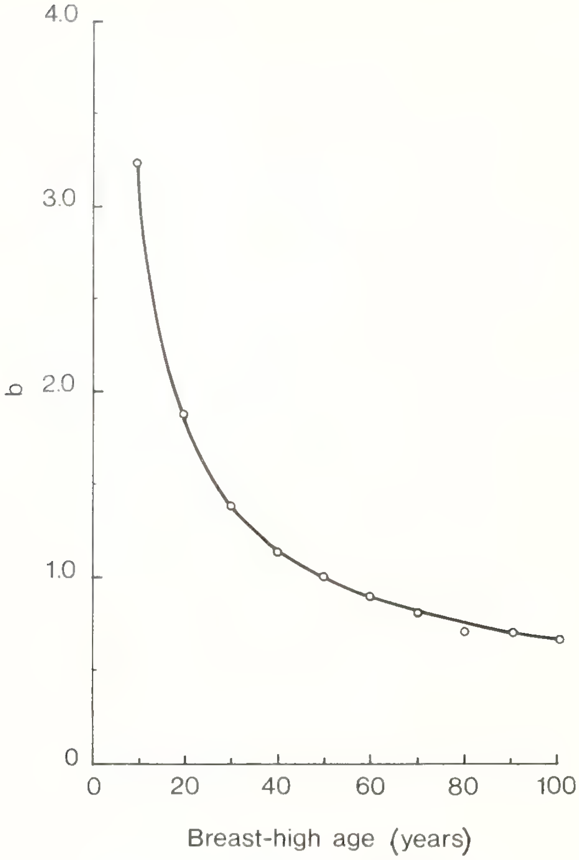


Figure 4.--b values in equation $SI - 4.5$ feet $= a + b\ (HT - 4.5$ feet$)$ as a function of age. Points are actual b values. Solid line is curve expressed by the equation, $\hat{b} = 0.52032 - 0.0013194\ age + 27.2823/age$.

The resulting $\hat{b}$ values are those appearing in table 1.

3. The following equation (with a standard error of 0.54 feet[6] and an R^2 of 0.9999), expressing decadal mean heights as a function of age, was conditioned to pass through mean site index (SI = 84.47) at 50 years (fig. 5):

$$\hat{HT} - 4.5 = e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e age)^4)}.$$

Here $\hat{HT}$ is an estimate of $\overline{HT}$. At ages beyond 50 years, the sample became progressively smaller and mean site index was slightly differen Average heights were adjusted to the mean overall site index using a_1 and b_1 values of the individual regressions of

$$HT - 4.5 = a_1 + b_1\ (SI - 4.5)$$

for each decade in the equation,

$$\text{Adjusted average height} - 4.5 \text{ feet} = a_1 + b_1\ (84.47 - 4.5)$$

before fitting the average height curve.

---

[6] These standard errors and R^2 values are for the equation as written, not its logarithmic form.

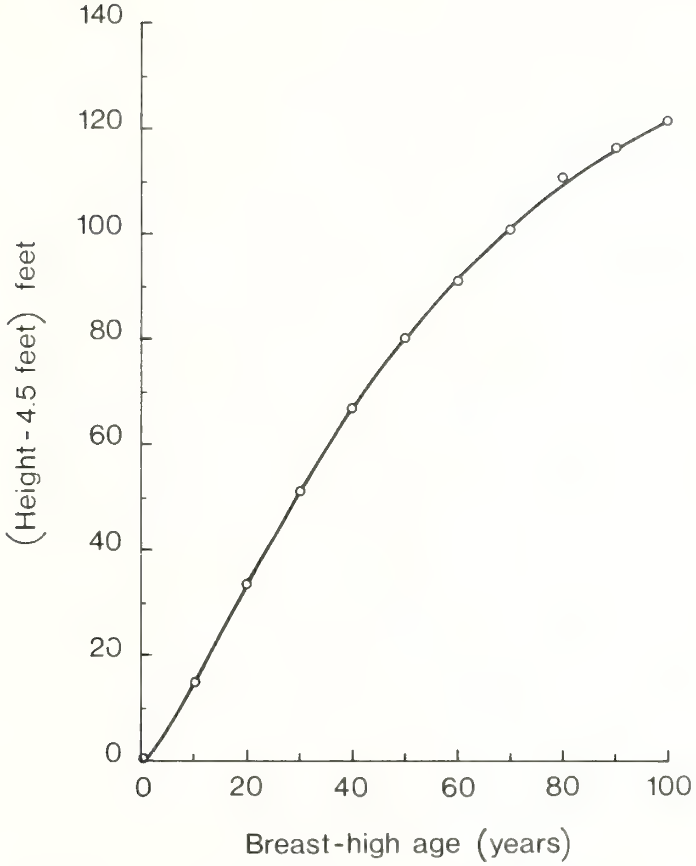


Figure 5.--Average height of sectioned trees as a function of breast-high age. Points are average heights - 4.5 feet. Solid line is curve expressed by the equation,

$$\overline{HT} - 4.5 \text{ feet} = e^{(-0.37496 + 1.36164 (\log_e age) - 0.00243434 (\log_e age)^4)}.$$

4. HT and the smoothed slope b of regressions for each year were hen used to calculate the corresponding intercept a:

$$\hat{a} = \overline{SI} - 4.5 - \hat{b}\,(\hat{HT} - 4.5).$$

hese a values appear in table 1.

5. Substituting expressions for a, b, and HT in the basic equation f step 1 gives the final equation used to estimate site index as a unction of breast-high age and height (fig. 3).

$$\begin{aligned} SI = 84.47 - & \left[e^{(-0.37496 + 1.36164 (\log_e age) - 0.00243434 (\log_e age)^4)}\right] \\ & \cdot (0.52032 - 0.0013194\ age + 27.2823/age) \\ & + (HT - 4.5)(0.52032 - 0.0013194\ age + 27.2823/age). \end{aligned}$$

HEIGHT GROWTH CURVE CONSTRUCTION

1. For height growth curve construction, the site indexes for each plot were related to the tallest heights at each decade by the equation,

$$HT - 4.5 = a_1 + b_1 \ (SI - 4.5);$$

the following estimates were obtained:

Breast-high age (years)	a_1	b_1	r^2	Standard error of the estimate	Number of observations
10	5.3429	0.1177	0.3803	2.50	32
20	.6967	.4103	.7681	3.75	32
30	-1.5405	.6584	.9096	3.45	32
40	-1.8455	.8576	.9713	2.45	32
50	0	1	1	0	32
60	3.4273	1.0950	.9831	2.40	30
70	6.1089	1.1837	.9519	4.53	28
80	2.8416	1.3477	.9498	5.51	18
90	9.5137	1.3358	.9486	5.43	10
100	10.4112	1.3889	.9399	6.13	10

2. The above decadal estimates of b_1 were smoothed over age (fig. 6) by the equation,

$$\hat{b}_1 = -0.2828 + 1.87947(1 - e^{-0.022399 \ age})^{0.966998};$$

the resulting $\hat{b}_1$ values are those appearing in table 2. The standard error and R^2 values are 0.0278 and 0.9969 for this equation which was forced through a b_1 value of 1 at age 50 years. These standard error and R^2 values are not measures of variation within the sampled population; they are given merely to show how well the fitted equation described the actual slope values for each decadal age.

3. The same expression for decadal height used in determing site index was used again with the mean site index (SI = 84.47) in a rearrangement of the basic equation,

$$\hat{a}_1 = \hat{HT} - 4.5 - \hat{b}_1 \ (\overline{SI} - 4.5)$$

to produce the a_1 values shown in table 2.

4. Appropriate rearrangement and substitution for a_1, b_1, and HT in the basic equation give the final equation used to estimate height as a function of age and site index as shown in figure 2:

$$HT = 4.5 + e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e age)^4)}$$

$$- 79.97 \ (-0.2828 + 1.87947 \ (1 - e^{-0.022399 \ age})^{0.966998}$$

$$+ (SI - 4.5) \ (-0.2828 + 1.87947 \ (1 - e^{-0.022399 \ age})^{0.966998}$$

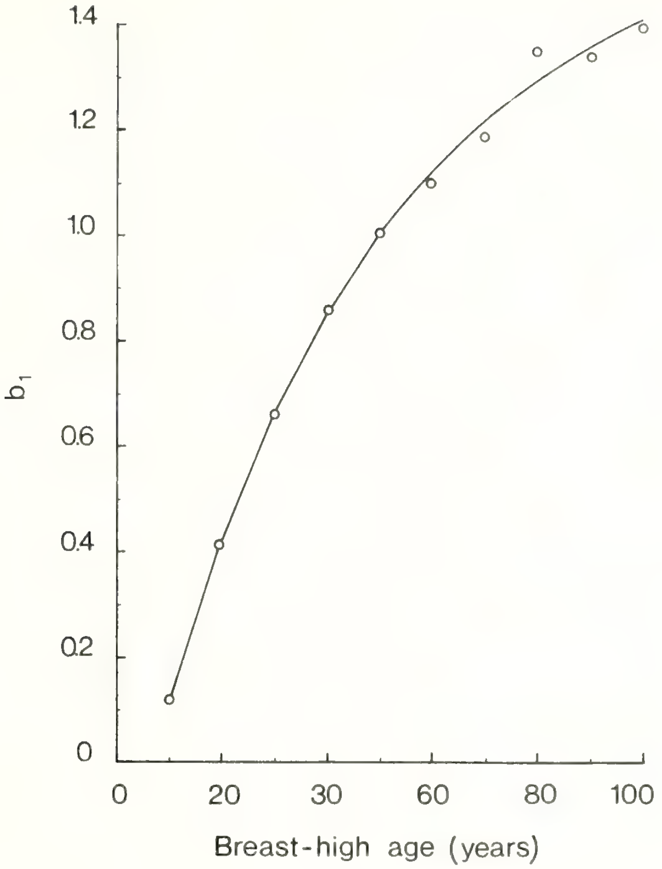


Figure 6.--b_1 values in the equation HT - 4.5 feet = a_1 + b_1 (SI - 4.5 feet) as a function of age. Points are actual b_1 values. Solid line is expressed by the equation,

$$\hat{b}_1 = -0.2828 + 1.87947\ (1 - e^{-0.022399\ age})^{0.966998}.$$

A graphic comparison between site index and the height growth curves is shown in figure 7.

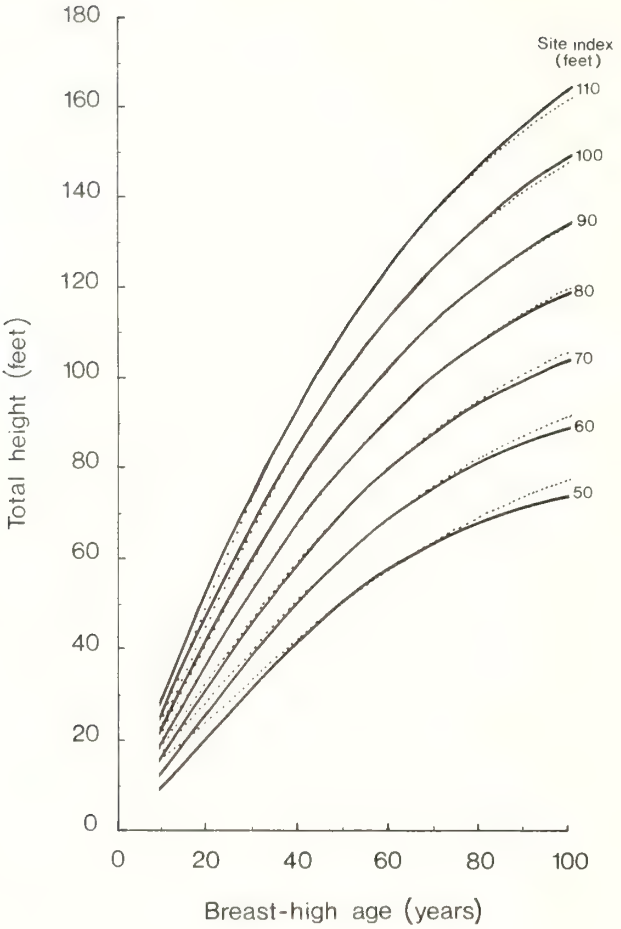


Figure 7.--Site index (solid lines) and height growth curves (dashed lines) for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest.

The final estimating equations for both site and height fit the basic data regression points well (figs. 8 and 9).

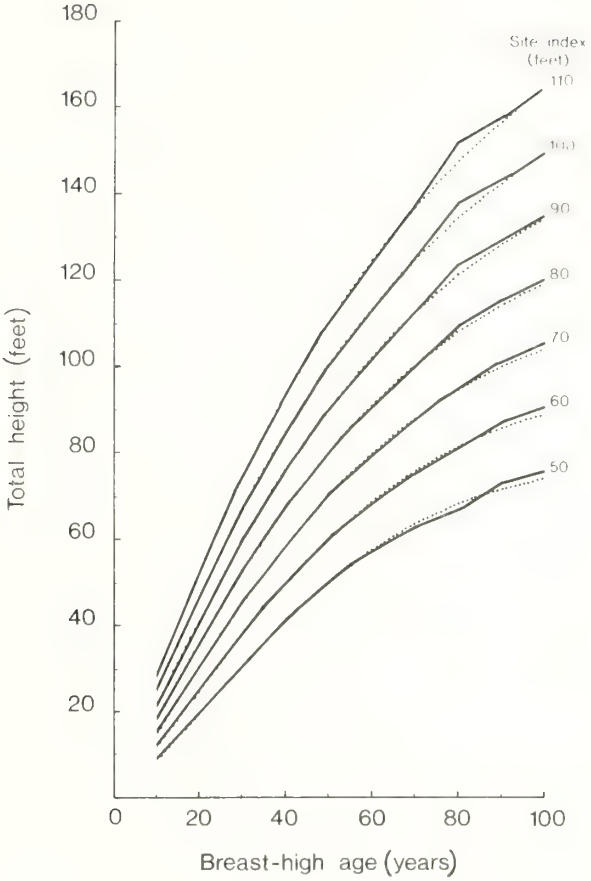


Figure 8.--Site index curves for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of the equation, $SI - 4.5 = a + b\,(HT - 4.5)$. *Dashed lines represent smooth curves from the following rearrangement of the estimating equation,*

$$HT = 4.5 + ((SI - 84.47) + (0.52032 - 0.0013194\ age + 27.2823/age))\,(e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e age)^4)})/(0.52032 - 0.0013194\ age + 27.2823/age).$$

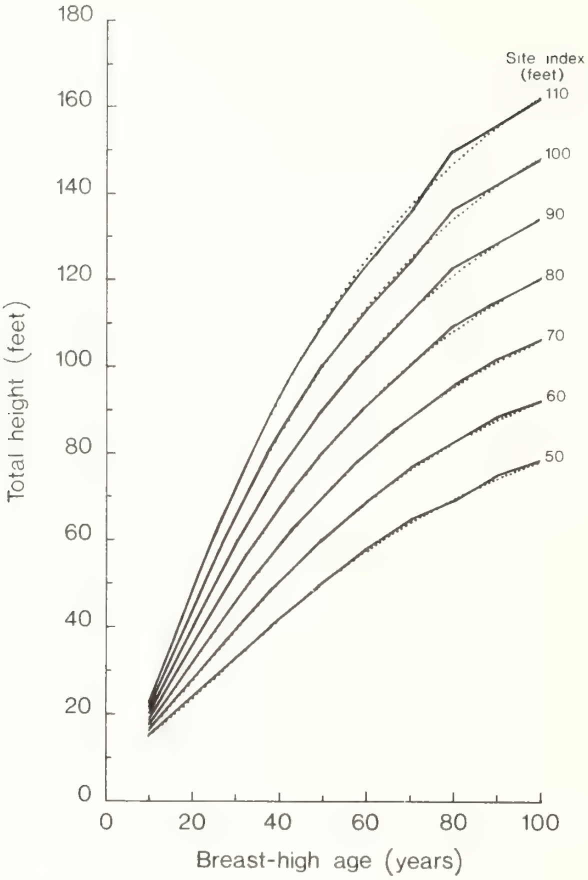


Figure 9.--Height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest. Solid lines connect decadal points derived from unsmoothed basic data regression of the equation,

$$HT - 4.5 = a_1 + b_1\ (SI - 4.5).$$

Dashed lines represent smooth curves from the estimating equations.

GPO 988-029

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Increment (height), site index, stem analysis, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Increment (height), site index, stem analysis, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Increment (height), site index, stem analysis, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Height growth and site index curves and equations for managed, even-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Increment (height), site index, stem analysis, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon (eastern), Washington (eastern).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

RESEARCH PAPER PNW-252
APRIL 1979

ITE INDEX AND EIGHT GROWTH CURVES FOR MANAGED, EVEN-AGED STANDS OF WHITE OR GRAND FIR EAST OF THE CASCADES IN OREGON AND WASHINGTON

CLEMSON UNIVERSITY LIBRARY
JUN 28 1979
SCI. TECH. & AGR. DIV.

GOVT. DOCUMENTS
DEPOSITORY ITEM

JUN 28

CLEMSON
LIBRARY

P. H. COCHRAN

usda • douglas-fir tussock moth • research & development program

IFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
DEPARTMENT OF AGRICULTURE PORTLAND, OREGON

Introduction

Over 9 million of the 20 million acres of commercial forest land in eastern Oregon and eastern Washington is in mixed conifer forests.[1] White fir (*Abies concolor* (Gord. & Glend.) Lindl.) or grand fir (*Abies grandis* (Dougl.) Lindl.)[2] is a component of many of these forests and often occurs in pure stands or mixed with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Engelmann spruce (*Picea engelmannii* Parry), western larch (*Larix occidentalis* Nutt.), or ponderosa pine (*Pinus ponderosa* Laws.). The site index and height growth curves presented here represent growth potential for grand or white fir in pure or mixed, even-aged, managed stands where relatively low density, lack of top damage, and absence of vegetative competition early in the life of the stand permit full height development. A managed stand is being manipulated toward some goal, usually a "target" average diameter and height within a set length of time. Some combination of precommercial and commercial thinnings and perhaps early suppression of competing vegetation will, at times, be employed. No stands exist that have been under this kind of management through a rotation. Therefore, I chose stands for sampling that approximated densities believed desirable in managed stands, not merely the average of existing stands. This work was conducted as part of the Douglas-fir Tussock Moth Research and Development Program. The results came from a study undertaken to ascertain potential production of stands susceptible to attack by tussock moth.

The site index curves and height growth curves in this publication are two separate sets of curves constructed for two different purposes. Site index curves are used to determine an index to potential production from current height and age. Height growth curves are used for describing the development of height growth as a function of age and site index in construction of yield tables (Curtis et al. 1974).

DATA COLLECTION

The data came from thirty-four 1/5-acre circular plots in pure and mixed stands (fig. 1) with these characteristics:

1. The average breast-high age was greater than 50 years. The stands were single storied, and at ground line the ages of the youngest trees were at least 80 percent of the ages of the oldest trees regardless of species.

---

[1] 1 acre = 0.4047 hectare.

[2] An *Abies grandis-A. concolor* species complex is recognized in the central Oregon Cascade Range. Farther south populations resemble *A. concolor*, whereas populations to the north become more like *A. grandis* (Zobel 1973). In this study no attempt was made to separate white and grand fir trees from each other or their hybrids. Data were handled as if they were one species.

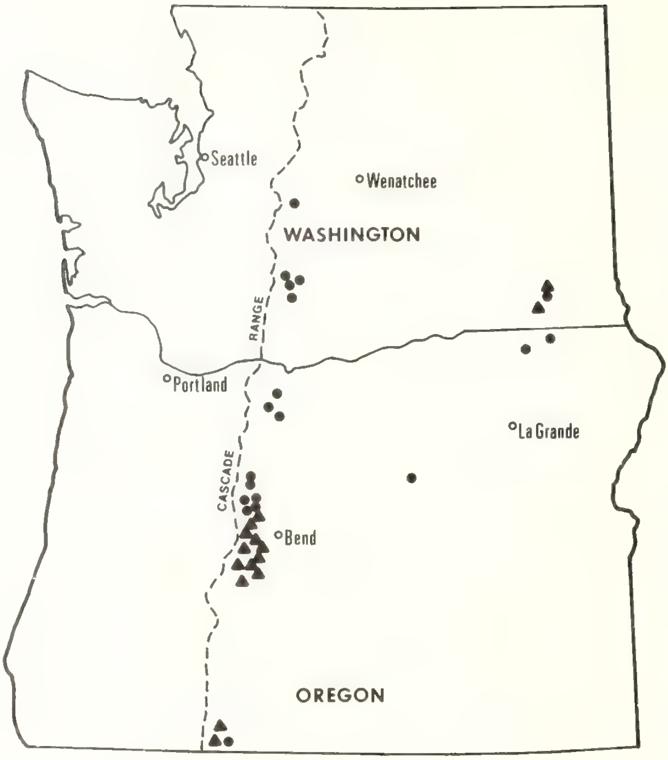


Figure 1.--Distribution of plots used in construction of curves. Triangles indicate plots where more than 80 percent of the basal area was white or grand fir. Solid circles represent mixed plots where 20 percent or more of the basal area consisted of conifer species other than white or grand fir.

2. The crown canopy was closed or nearly closed at the time of sampling. Mortality, if present, was due to suppression; and its volume was less than 5 percent of the plot volume. Stumps were absent. Volume growth patterns for the plot determined from stem analysis of at least 12 sample trees across the range of diameter classes indicated that the highest periodic annual volume increment had occurred within the last 15 years. These factors indicate that there was no severe competition between trees in the past.

3. The dominant trees on the plot did not contain a group of narrow annual rings, which would indicate stress in the past.

4. Trees were not visibly infected with disease or insects.

5. Dominant trees did not exhibit crook in the bole, and internodal lengths did not indicate past top damage. Several plots, including six in the area of Lakeview, Oregon, were rejected after sampling because the shape of the height growth curves suggested substantial top damage 30 or more years earlier, even though this damage was not apparent at the time of selection.

6. Clumps of trees were not sampled. The plots were in homogeneous stands, and each plot had a buffer strip equivalent in width to tree height.

Diameter at breast height (d.b.h.) for each tree in each plot was measured, and 15 trees of each species on each plot were felled to determine past periodic annual increments for the plot. Included in this group were the three largest diameter trees of each species. If taller trees existed on the plot, they were felled and their stem analysis data used for construction of the site index and height growth curves but not in volume growth determinations. The two to five tallest trees of each species at the time of sampling were sectioned at a 1-foot stump, 4.5 feet (bh), 10 feet, and then at 10-foot intervals up the stem after total height was measured.[3] Sections at ground line were also taken from at least two of the largest diameter trees, two of the smallest diameter trees, and one tree with close to the mean diameter. Rings were counted for all sections and recorded for the appropriate height.

CURVE CONSTRUCTION

An age of 50 years at breast height (4.5 feet) was chosen as the index age. For each plot, total heights of each of the three to five tallest trees were plotted as a function of bh age for each tree on a single sheet of graph paper. The bh age for each tree was used as the independent variable in the initial plotting rather than average bh age for two reasons: (1) Height growth to 4.5 feet seems to be greatly influenced by competition immediately adjacent to a seedling and perhaps by early animal damage. Thus, it is possible for dominant trees of the same species to be the same age at ground line but to differ as much as 10 years at 4.5 feet. In this case, use of an average bh age for plotting heights results in an underestimate of the height growth potential of the site. (2) Use of an average bh age for mixed species when heights are plotted as a function of age does not give a realistic picture of height growth for each species. For mixtures of seedlings germinating the same year, larch reaches bh height first, followed by the pines, then Douglas-fir, and finally white or grand fir. There will usually be more than a 5-year bh age spread between the larch and the white or grand fir.

In plotting, shifts in relative position of individual trees occurred for the white or grand fir on 50 percent of the plots. These shifts in the tree of maximum height for its bh age indicate that the tree that was tallest for its bh age at the time of sampling was not always tallest for its bh age in the past.

Freehand curves were drawn for each tree on the single sheet of graph paper for each plot, and the highest points at each decadal age were used in subsequent construction of curves. Site index for white or grand fir on each plot was defined as the tallest height for that species complex at bh age 50.

From this point the methodology outlined by Barrett (1978) is used; it includes the recent improvements in curve construction methods suggested by Curtis et al. (1974) and Dahms (1975). Tabulations and figures used in construction of the curves are presented in the appendix. For aid in understanding this appendix, these tabulations and figures can be compared with similar data and explanations for Douglas-fir (Cochran 1979).

---

[3] 1 foot = 0.3048 meter.

Some understanding of how the curves were constructed is helpful for proper use of the curves. Therefore, it is suggested that even occasional users of these curves read the appendix.

The 34 plots used in construction of curves for white fir or grand fir had site indexes ranging from 63.5 to 130 feet although only 1 sample plot had a site index above 110 feet. Average site index was 89.43 feet:

Number of plots of white fir or grand fir	Site index (feet)
0	50-59
2	60-69
7	70-79
5	80-89
14	90-99
5	100-109
1	>110

Results and Application

Site index curves (fig. 2) can be used for rough field estimates of site index. For a more precise estimate, the appropriate a and b values in table 1 can be used to solve the equation,

$$\text{Site index} - 4.5 \text{ feet} = a + b\,(\text{height} - 4.5 \text{ feet}).$$

The equation,

$$\text{Site index} = (\text{height} - 4.5 \text{ feet})(e^{x1}) - e^{x1}\,(e^{x2} \text{ feet}) + 89.43 \text{ feet},$$

can be used with a calculator; $x1 = 3.8886 - 1.8017\,(\log_e \text{age}) + 0.2105\,(\log_e \text{age})^2 - 0.0000002885\,(\log_e \text{age})^9 + 0.0000000000000000001187\,(\log_e \text{age})^{24}$, and $x2 = -0.30935 + 1.2383\,(\log_e \text{age}) + 0.001762\,(\log_e \text{age})^4 - 0.0000054\,(\log_e \text{age})^9 + 0.0000002046\,(\log_e \text{age})^{11} - 0.000000000000404\,(\log_e \text{age})^{18}$.

Age in all equations in this paper is at breast height.

The following steps should be used in applying any of the procedures for estimating site index:

1. Select suitable plots with the following characteristics:
    - (a) Even-aged at the ground line; no older remnants from earlier stands; present stand one-storied.
    - (b) No visible symptoms of disease or insect attack to reduce height growth.
    - (c) No narrow ring groups to indicate suppression.
    - (d) No sign of damage on internodal lengths on taller trees.

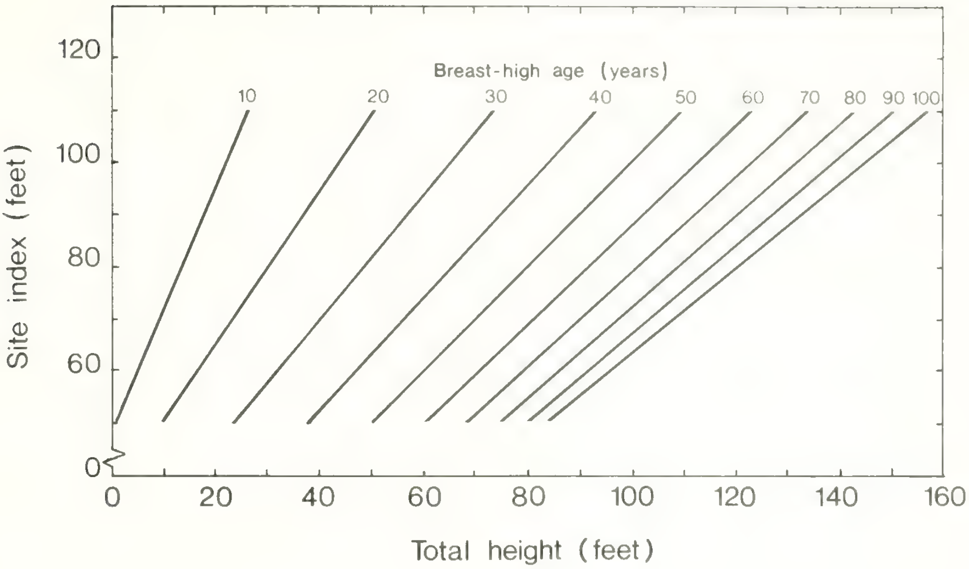


Figure 2.--Site index curves for managed, even-aged stands of white or grand fir east of the Cascades in the Pacific Northwest.

Table 1--Values for a and b by years for the family of regressions[1] *for estimating site index for white or grand fir east of the Cascades in the Pacific Northwest) derivation of these a and b values is described in the appendix)*

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	53.778	2.353	52.315	2.177	50.808	2.035	49.266	1.917	47.699	1.819	46.112	1.735	44.511	1.663	42.903	1.600	41.290	1.546	39.678	1.497
20	38.069	1.455	36.467	1.416	34.876	1.382	33.296	1.350	31.732	1.322	30.185	1.296	28.656	1.273	27.149	1.251	25.663	1.231	24.201	1.212
30	22.764	1.195	21.353	1.179	19.968	1.164	18.612	1.150	17.283	1.137	15.983	1.125	14.711	1.113	13.470	1.102	12.257	1.092	11.075	1.082
40	9.922	1.073	8.799	1.064	7.706	1.056	6.641	1.048	5.607	1.040	4.601	1.033	3.624	1.026	2.675	1.019	1.754	1.012	.860	1.006
50	0	1.000	-.846	.994	-1.659	.989	-2.447	.983	-3.210	.978	-3.948	.973	-4.662	.968	-5.353	.963	-6.020	.958	-6.665	.954
60	-7.288	.949	-7.889	.945	-8.469	.941	-9.029	.936	-9.569	.932	-10.090	.928	-10.591	.924	-11.074	.920	-11.539	.917	-11.987	.913
70	-12.417	.909	-12.831	.906	-13.228	.902	-13.609	.899	-13.975	.895	-14.326	.892	-14.661	.888	-14.983	.885	-15.290	.882	-15.584	.878
80	-15.863	.875	-16.130	.872	-16.384	.869	-16.625	.866	-16.853	.863	-17.069	.859	-17.273	.856	-17.466	.853	-17.646	.850	-17.815	.847
90	-17.973	.844	-18.119	.842	-18.255	.839	-18.379	.836	-18.493	.833	-18.596	.830	-18.688	.827	-18.770	.824	-18.841	.823	-18.901	.819
100	-18.951	.816																		

[1] To estimate site index, measure total height of up to 5 tallest trees per 1/5-acre plot; determine breast-high age for each. Select appropriate a and b values above. Substitute values in the equation, Site index - 4.5 feet = a + b (height - 4.5 feet). For example, for a tree 53 years old at breast height and 80 feet in total height, solve the equation, Site index - 4.5 feet = -2.447 feet + 0.983 (80 feet - 4.5 feet), for a site index of 78.7 feet. Determine the site index for each sample tree. The highest site index determined is the site index for white or grand fir on the 1/5-acre plot.

(e) Little remnant understory vegetation or suppression mortality to indicate competition early in the life of the stand and possible reduction of height growth.

2. Establish boundaries of 1/5-acre plot with a prespecified shape.
3. Measure the height of up to five tallest dominant or codominant white or grand fir and Douglas-fir, if present, on the plot.
4. Extract increment cores from these trees to determine their breast-high age.
5. Using the breast-high age and total height for each tree, determine a site index value for each tree. Curves, tables, and equations for Douglas-fir are given by Cochran (1979).
6. Record for each species on each plot the highest value obtained for site index.
7. The site index for the area of concern would be the average of the highest site indexes determined on the 1/5-acre sample plots. As will be pointed out, there may be no practical differences between the site indexes of white or grand fir and Douglas-fir. Therefore, in stands that are mixtures of Douglas-fir and white or grand fir, I recommend averaging the highest site indexes of each plot regardless of species. It is very important to use accurate age and height measurements; bias from height measurement error could easily occur.

Height growth curves (fig. 3) define the average pattern of height development for the tallest trees in stands of a given site quality. They are appropriately used for constructing yield tables but do not provide optimum estimates of site index from measured height and age in an existing stand (Curtis et al. 1974). Comparisons of height growth curves and site index curves are given in figure 4.

The following are alternatives for estimating the anticipated height of the tallest trees of a managed, even-aged stand on land of known site index:

1. Use figure 2 for rough field estimates.
2. For more precise estimates, use table 2 to solve the equation:

$$\text{Total height} - 4.5 \text{ feet} = a_1 + b_1 (\text{site index} - 4.5 \text{ feet}).$$

3. The estimating procedure can be programed on a calculator using the equation,

$$\text{Total height} - 4.5 \text{ feet} = e^{x2} \text{ feet} - (84.93 \text{ feet})\, e^{x3} + (\text{site index} - 4.5 \text{ feet})\, e^{x3}.$$

Here, x2 is as previously defined, and

$$x3 = -6.2056 + 2.097 \log_e \text{age} - 0.09411 (\log_e \text{age})^2 - 0.00004382 (\log_e \text{age})^7 + 0.0000000002007 (\log_e \text{age})^{16} - 0.00000000000000002054 (\log_e \text{age})^{24}.$$

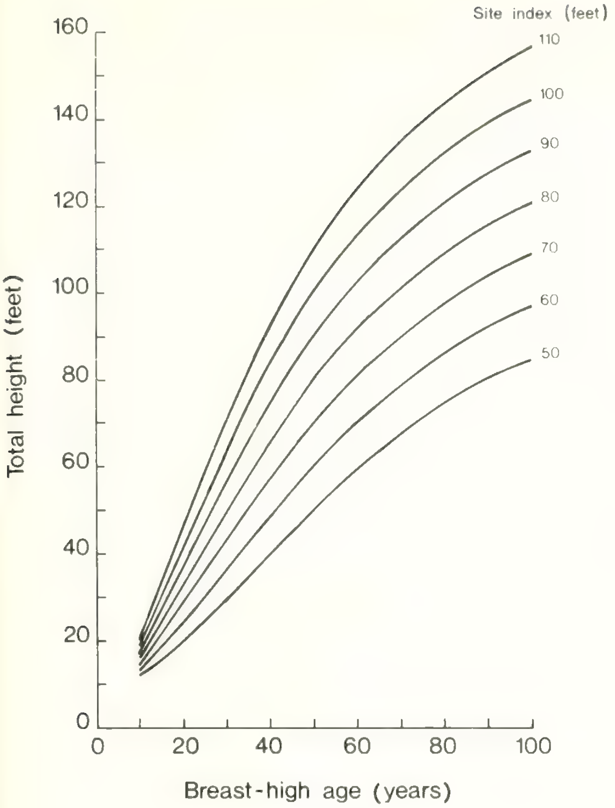


Figure 3.--Height growth curves for grand or white fir east of the Cascades in managed, even-aged stands.

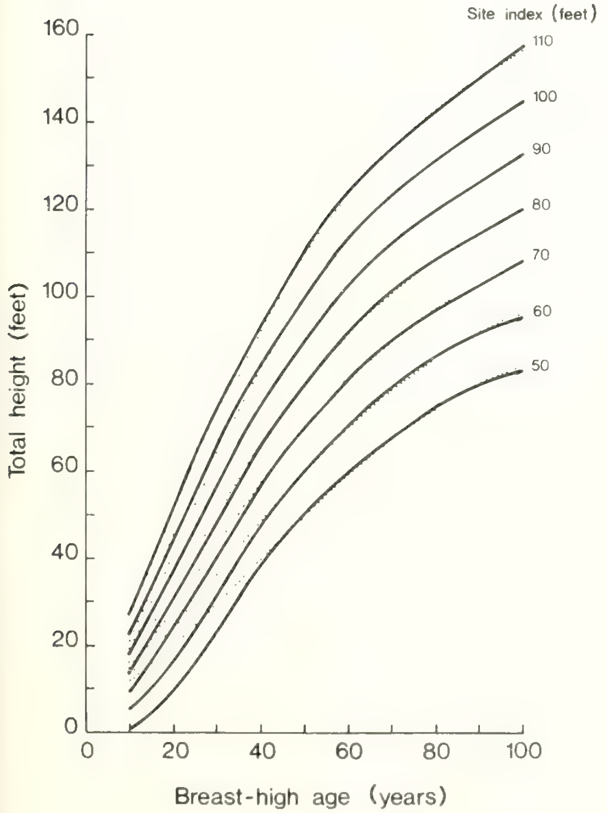


Figure 4.--Site index (solid lines) and height growth curves (dashed lines) for white or grand fir in managed, even-aged stands east of the Cascades in Oregon and Washington.

Table 2--Values for a_1 and b_1 by years for the family of regressions[1] *for estimating height of the tallest trees in a newly established stand of white or grand fir where site index and age are known (derivation of a_1 and b_1 values is described in the appendix)*

reast high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
ears																				
10	0.423	0.151	0.048	0.176	-0.353	0.202	-0.771	0.228	-1.200	0.255	-1.631	0.283	-2.060	0.310	-2.481	0.338	-2.888	0.366	-3.278	0.3
20	-3.648	.422	-3.993	.450	-4.312	.477	-4.602	.504	-4.861	.531	-5.088	.557	-5.280	.583	-5.438	.608	-5.561	.632	-5.647	.6
30	-5.698	[illegible]	-5.712	.702	-5.690	.724	-5.633	.745	-5.540	.766	-5.412	.785	-5.251	.805	-5.057	.823	-4.830	.840	-4.572	.8
40	-4.285	.874	-3.968	.889	-3.624	.904	-3.253	.918	-2.857	.932	-2.437	.945	-1.995	.957	-1.532	.969	-1.048	.980	-.546	.9
50	0	1.000	.508	1.010	1.058	1.019	1.621	1.027	2.196	1.035	2.782	1.043	3.378	1.050	3.981	1.057	4.592	1.063	5.209	1.0
60	5.831	1.075	6.457	1.081	7.085	1.086	7.715	1.091	8.346	1.095	8.976	1.100	9.605	1.104	10.233	1.108	10.857	1.111	11.477	1.1
70	12.093	1.118	12.704	1.121	13.308	1.125	13.905	1.127	14.495	1.130	15.077	1.133	15.649	1.136	16.212	1.138	16.765	1.141	17.308	1.1
80	17.839	1.146	18.358	1.148	18.865	1.151	19.359	1.153	19.840	1.156	20.307	1.158	20.760	1.161	21.198	1.163	21.621	1.166	22.029	1.1
90	22.421	1.171	22.798	1.173	23.157	1.176	23.500	1.179	23.825	1.182	24.133	1.184	24.424	1.187	24.696	1.190	24.950	1.193	25.186	1.1
100	25.403	1.200																		

[1] Height at a future date of the tallest portion of a young stand may be estimated on land of known site index by selecting a_1 and b_1 values for the ppropriate breast-high age. Substitute a_1 and b_1 values in the equation, Height - 4.5 feet = a_1 + b_1 (Site index - 4.5 feet). For example, to determine he height of the tallest trees in the stand at breast-high age 75 on land with a known site index of 100 feet, solve the equation, Height - 4.5 feet = 5.077 feet + 1.133 (100 feet - 4.5 feet), for a total height of 126.3 feet.

Data for these curves were collected from natural, even-aged stands where densities prior to sampling resembled those assumed desirable in the managed stands of the future. Therefore, use of these curves should be restricted to managed, even-aged stands where height growth has not been reduced by stand density. The curves should not be used for:

1. Precommercially thinned stands showing a tight core of rings.
2. Commercially thinned stands with numerous stumps indicating a high initial density.
3. Plantations with large numbers of trees thinned long after competition between trees occurred.
4. Stands where height growth was severely restricted by brush competition early in the life of the stand. This usually results in a tight core of rings at the center of the b.h. increment core and should be watched for in widely spaced older stands that appear to have never experienced severe competition.

These curves may have limited application in the field for some time because only a small amount of land under management fits the constraints of the curves. Greatest use is in forecasting future stand performance in stand growth simulators.

Reliability of the curves can be partially determined by the r^2 values and standard errors associated with the slope and intercept values of the basic equations. This information is presented in the appendix. Also, one may judge the equation fit from figures 5 and 6.

There were 13 plots that had both dominant Douglas-fir and dominant white or grand fir trees. Site index values for Douglas-fir were determined as outlined by Cochran (1979) and compared with the site index values obtained for the white or grand fir. For these plots, the relationship between the site indexes of the two species is (r^2 = 0.7942; standard error = 4.2 feet):Douglas-fir SI = -2.7894 + 1.0367 (white or grand fir SI).

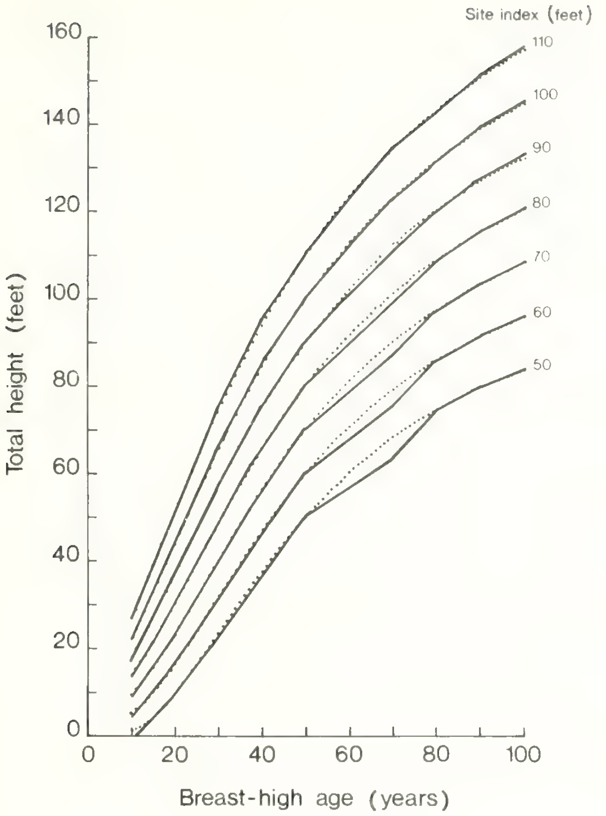


Figure 5.--Site index curves for managed, even-aged stands of white or grand fir east of the Cascades in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of SI - 4.5 feet = a + b (HT - 4.5 feet). Dashed lines represent smooth curves from a rearrangement of the estimating equation.

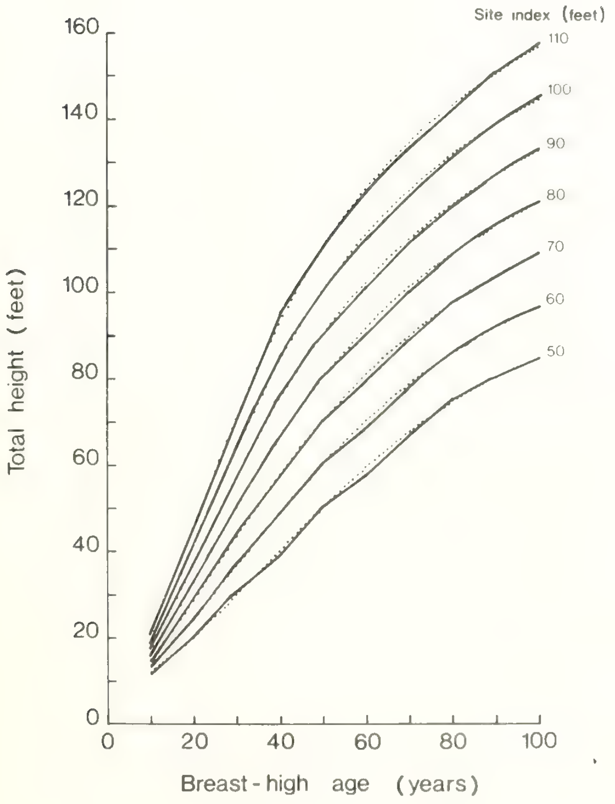


Figure 6.--Height growth curves for managed, even-aged stands of white or grand fir in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of HT - 4.5 feet = $a_1 + b_1$ (SI - 4.5 feet). Dashed lines represent smooth curves from the estimating equation.

Although the relationship of site indexes between species needs more investigation, it may indicate that within the ranges of sites where these species occur as mixtures there is no practical difference in the 50-year-bh-age-base site index between the two species even though the shapes of the curves are different.

Literature Cited

Barrett, James W.
1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1979. Site index and height growth curves for Douglas-fir in managed, even-aged stands east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Curtis, Robert O., Donald J. DeMars, and Francis R. Herman.
1974. Which dependent variable in site index-height age regressions? For. Sci. 20(1):74-87.

Dahms, Walter G.
1975. Gross yield of central Oregon lodgepole pine. *In* Management of lodgepole pine ecosystems symposium proceedings, p. 208-232, illus. David M. Baumgartner, ed. Wash. State Univ. Coop. Ext. Serv., Pullman.

Zobel, Donald B.
1973. Local variation in intergrading *Abies grandis-Abies concolor* populations in the central Oregon Cascades: Needle morphology and periderm color. Bot. Gaz. 134(3):209-220.

Appendix

In construction of both site index and height growth curves, a curve of average height for the samples as a function of age at 4.5 feet is determined. This height curve is then adjusted upward or downward to the desired site index using the linear relationship existing between height and site index at any age with appropriate estimates of slope and intercept. The curves are different because slope and intercept values of the basic equations,

$$SI - 4.5 \text{ feet} = a + b\,(HT - 4.5 \text{ feet}) \text{ and}$$

$$HT - 4.5 \text{ feet} = a_1 + b_1\,(SI - 4.5 \text{ feet}),$$

are different for all ages except the index age (50 years at bh for these curves).

Values for a, b, a_1, and b_1 are determined for each 10-year-bh age interval using heights for each 10-year interval and site indexes tabulated from the freehand curves for the sample plots. The b and b_1 values are then smoothed (figs. 7 and 8) by fitting equations which describe b and b_1 as a function of breast-high age. Each of these equations are forced through 1 at age 50.

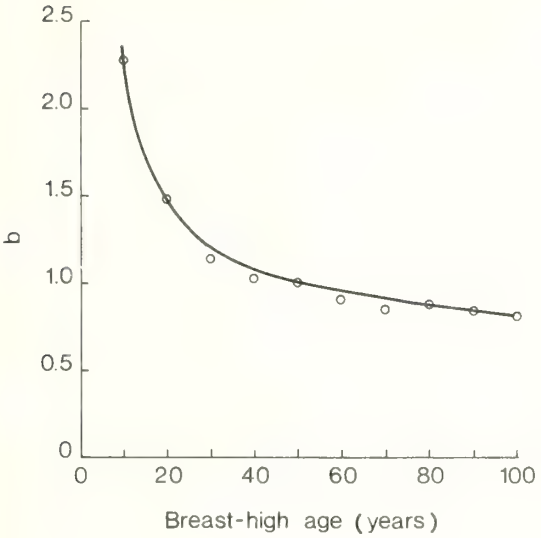


Figure 7.--b values in the equation $SI - 4.5\ \text{feet} = a + b\ (HT - 4.5\ \text{feet})$ as a function of age. Plotted points are actual b values. Solid lines are curves expressed by the equation $\hat{b} = e^{x1}$. Coefficient x1 is defined in the text. Standard error is 0.063, and R^2 equals 0.9891.

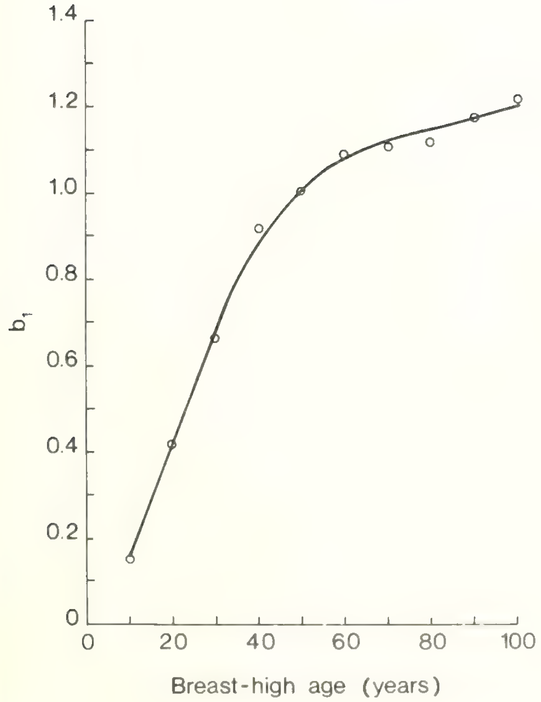


Figure 8.--b values in the equation $HT - 4.5\ \text{feet} = a_1 + b_1\ (SI - 4.5\ \text{feet})$ as a function of age. Plotted points are actual b_1 values. Solid lines are curves expressed by the equation $\hat{b}_1 = e^{x3}$. Coefficient x3 is defined in the text. Standard error and R^2 values are 0.031 and 0.9966, respectively.

The R^2 and standard error values associated with the b and b_1 values in figures 7 and 8 are given merely to show how well the fitted equations describe the slope values for each decadal age. These measures of variation have no direct association with the original population. Next, an average height curve is defined (fig. 9). For ages where the sample size decreases, points for fitting the height curve are determined by using actual a_1 and b_1 values from the regression calculated for that age and the average site index for all the plots in:

$$HT - 4.5 \text{ feet} = a_1 + b_1 \ (\overline{SI} - 4.5 \text{ feet}).$$

In fitting the average height curve, the equation describing HT - 4.5 feet as a function of bh age is forced through the average site index - 4.5 feet at bh age 50 years.

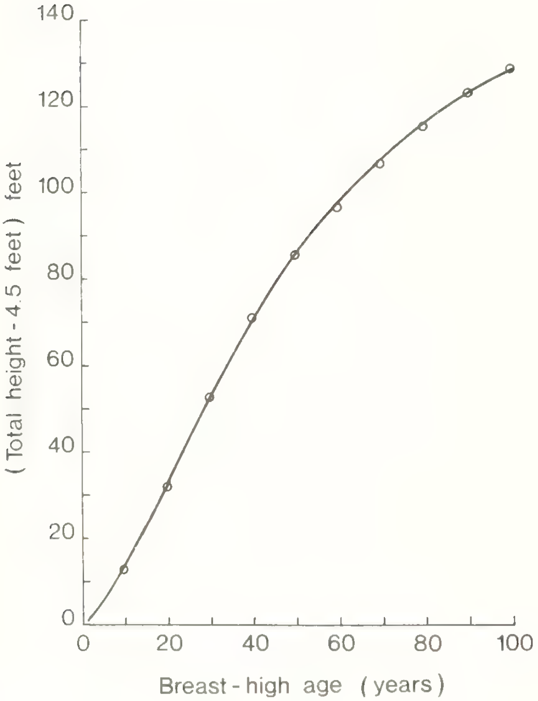


Figure 9.--Average height of sectioned trees as a function of breast-high age. Plotted points are actual average heights minus 4.5 feet. Solid lines are curves expressed by the equation $\hat{HT}$ - 4.5 feet = e^{x2}. Coefficient x2 is defined in the text. The standard error is 1.25 feet, and R^2 equals 0.995.

Once equations for the smoothed $\hat{b}$ and $\hat{b}_1$ values and the average height curve are obtained, equations for the smoothed $\hat{a}$ and $\hat{a}_1$ values in tables 1 and 2 and the equations for the site index and height growth curves are obtained by substitution of appropriate expressions and rearrangement of the basic equations. All b and b_1 values are without units; all a and a_1 values have units of feet.

Following are some estimates for the equation SI - 4.5 feet = a + b (HT - 4.5 feet), where HT = total height and SI = site index:

White or grand fir, bh age	a	b	r^2	Standard error of the estimate	Number of observations
(Years)	(Feet)	(Feet)		(Feet)	
10	56.3805	2.2724	0.3423	10.85	34
20	38.3353	1.4729	.6086	8.37	34
30	25.7738	1.1341	.7492	6.70	34
40	13.1296	1.0211	.9373	3.35	34
50	0	1	1	0	34
60	-1.1024	.9001	.9773	2.01	33
70	-4.1854	.8438	.9316	3.73	23
80	-15.5229	.8768	.9782	2.01	13
90	-17.2781	.8363	.9820	1.83	8
100	-18.5481	.8091	.9839	1.74	8

The eight plots with bh ages of 90 years and above have site indexes of 63.5, 74.8, 75, 75.5, 86.5, 90, 94.5, and 102 feet.

Some estimates follow for the equation HT - 4.5 feet = a_1 + b_1 (SI - 4.5 feet):

White or grand fir, bh age	a_1	b_1	r^2	Standard error of the estimate	Number of observations
(Years)	(Feet)	(Feet)		(Feet)	
10	-0.2285	0.1506	0.3423	2.79	34
20	-3.4601	.4132	.6086	4.32	34
30	-3.9426	.6606	.7492	5.11	34
40	-7.6391	.9179	.9373	3.18	34
50	0	1	1	0	34
60	3.3556	1.0858	.9773	2.21	33
70	11.8894	1.1041	.9316	4.27	23
80	19.7133	1.1157	.9782	2.27	13
90	22.3436	1.1743	.9820	2.17	8
100	24.4805	1.2161	.9839	2.13	8

* * * * * * *

GPO 988-033

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Height growth and site index curves and equations for white or grand fir growing in managed, even-aged pure stands or mixed with other conifers east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Site index, increment (height), stem analysis, measurement systems, even-aged stands, white fir, *Abies concolor*, grand fir, *Abies grandis*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Height growth and site index curves and equations for white or grand fir growing in managed, even-aged pure stands or mixed with other conifers east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Site index, increment (height), stem analaysis, measurement systems, even-aged stands, white fir, *Abies concolor*, grand fir, *Abies grandis*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Height growth and site index curves and equations for white or grand fir growing in managed, even-aged pure stands or mixed with other conifers east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Site index, increment (height), stem analysis, measurement systems, even-aged stands, white fir, *Abies concolor*, grand fir, *Abies grandis*, Oregon (eastern), Washington (eastern).

Cochran, P. H.
1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Height growth and site index curves and equations for white or grand fir growing in managed, even-aged pure stands or mixed with other conifers east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently has not been suppressed by high density or top damage.

KEYWORDS: Site index, increment (height), stem analysis, measurement systems, even-aged stands, white fir, *Abies concolor*, grand fir, *Abies grandis*, Oregon (eastern), Washington (eastern).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

RESEARCH PAPER PNW-253

APRIL 1979

Fifty-year Development of Douglas-fir Stands Planted at Various Spacings

GOVT. DOCUMENTS
DEPOSITORY ITEM
SEP 12 1979
CLEMSON
LIBRARY

CLEMSON UNIVERSITY LIBRARY
SEP 17 1979
CLEM. AGR & TECH

Donald L. Reukema

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

CONTENTS

Page

INTRODUCTION. 1

THE STUDY 1
  Study Area. 1
  Treatment 1
  Sampling and Measurements 2

RESULTS AND DISCUSSION 3
  Number of Trees 3
  Height and Site Quality 6
  Diameter. 9
  Basal Area. 11
  Cubic Volume. 13

CONCLUSIONS AND MANAGEMENT IMPLICATIONS . . 18

LITERATURE CITED. 20

APPENDIX. 21
  Fitted Curves 21
  Adjustments for Plot Size 21
  D.b.h. Distribution 21

METRIC CONVERSION FACTORS

1 inch.	2.54 centimeters
1 foot.	0.3048 meters
1 acre.	0.4047 hectares
1 tree/acre	2.471 trees/hectare
1 square foot/acre.	0.2296 square meters/hectare
1 cubic foot/acre .	0.06997 cubic meters/hectare

Fifty-Year Development of Douglas-fir Stands Planted at Various Spacings

eference Abstract

eukema, Donald L.
1979. Fifty-year development of Douglas-fir stands planted at
various spacings. USDA For. Serv. Res. Pap. PNW-253, 21 p.,
illus. Pacific Northwest Forest and Range Experiment Station,
Portland, Oregon.

A 51-yr record of observations in stands planted at six spacings, anging from 4 to 12 ft, illustrates clearly the beneficial effects f wide initial spacing and the detrimental effects of carrying too any trees relative to the size to which they will be grown. Not nly are trees larger, but yields per acre are greater at wide spacings.

EYWORDS: Plantation spacing (-growth, stand density, stand development, Douglas-fir, *Pseudotsuga menziesii*.

esearch Summary

esearch Paper PNW-253

979

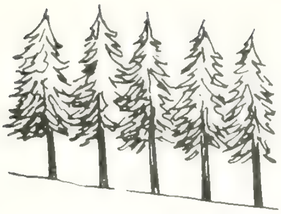
A 51-yr record of observations n Douglas-fir stands planted on ite IV land at six different pacings--ranging from 4 to 12 ft 1.2 to 3.7 m)--illustrates very learly the beneficial effects of ide initial spacing. It also llustrates the deterimental ffects of carrying too many rees relative to the size to hich they will be grown. Pri-arily as a result of initial pacing, average site index is urrently 50 percent higher at he widest spacing than at the losest spacings. Differences etween wide and close spacings y all measures of production re closely related to these ifferences in site index. Thus, ot only are trees larger, but ield per acre is greater at ide spacings. Furthermore, most f this volume is contained in merchantable-size trees at wide spacings, whereas much of it is in submerchantable trees at closer spacings.

At age 53 (from seed), the 100 largest trees per acre (250/ha) are about 75 percent larger in d.b.h. and 60 percent taller at 12-ft than at 4-ft spacing. Corresponding diameters and heights are 13.6 vs. 7.8 inches (34.5 vs. 19.8 cm) and 95 vs. 60 ft (29 vs. 18 m). Gross volume production of the total stand to age 53 ranges from about 4,230 to 6,680 ft^3 per acre (296 to 467 m^3/ha), at 4- and 10-ft (1.2- and 3.0-m) spacings; corresponding volumes in live trees are 3,550 and 6,420 ft^3 per acre (248 and 449 m^3/ha). Volumes of the 100 largest trees per acre (250/ha) range from about 850 to 3,840 ft^3 per acre (59 to 269 m^3/ha), at 4- and 12-ft spacings. *Total* yield is nearly as great at 12- as at 10-ft spacing; *merchantable* yield is greater at the 12-ft spacing.

Whereas current annual volume increment (c.a.i.) of the total stand has declined with increasing age, c.a.i. of the 100 largest trees per acre has tended to remain nearly constant over the past 24 years. Mean annual increment (m.a.i.) is near culmination at close spacings, but is still far short of culmination at wide spacings.

The impact of mortality has been minor at wide spacings. At close spacings, however, much mortality was the result of snow and ice damage, which affected groups of trees and created openings in the crown canopy. This has reduced occupancy of the site and caused a further *indirect* loss in usable production.

These trends indicate that differences--in favor of wide spacings--will continue to increase.



INTRODUCTION

A Douglas-fir spacing trial established in 1925 at Wind River Experimental Forest, near Carson, Washington, has been observed periodically for over 50 years. These observations have provided an increasingly valuable record of long-term effects of initial spacing on subsequent stand development. Earlier results were reported by Isaac (1937), Munger (1946), Eversole (1955), Reukema (1959, 1970), and Curtis and Reukema (1970). This paper updates previously published information by 10 years. It also provides more information on stand components, growth trends, and relationships between the 100 largest trees per acre and the total stand.

THE STUDY

Study Area

Wind River Experimental Forest lies just north of the Columbia River Gorge, which bisects the Cascade Range. The climate of the area is wet, with average precipitation about 100 inches (250 cm) per year. The average annual snowfall is about 80 inches (200 cm). Most precipitation falls during 9 months of the year; summers are quite dry. The frost-free season averages about 120 days.

The spacing test plantations occupy a site IV alluvial flat at an elevation of about 1,300 feet (400 m). Felled old growth on the area was accidentally burned in 1920, after which all usable material was salvaged. A reburn in 1924 destroyed all reproduction and burned all duff and small debris down to mineral soil. Some spots were burned very heavily. Subsequent analyses showed that this heavy burning had reduced the moisture-holding capacity and released nitrogen from the soil.[1]

Soils are generally 5 to 10 feet (1.5 to 3.0 m) deep, well-drained and slightly acid. Surface soils are sandy loams; subsoils are loam, silt loam, or clay loam, with 0 to 30 percent small shot and gravel.[2] Soils are underlain by an olivine basalt flow. Despite the apparent uniformity of the site, there are local variations in site quality.

Treatment

In the spring of 1925, 1+1 seedlings were planted in 2.8-acre (1.1-ha) blocks at square spacings of 4, 5, 6, 8, and 10 feet (1.2, 1.5, 1.8, 2.4, and 3.0 m). Surplus seedlings were planted in a 0.5-acre (0.2-ha) block at 12-ft (3.7-m) spacing. These seedlings were started in the Wind River Nursery. Source(s) of seed is unknown, but it appears to be compatible with the planting site.

Extra seedlings were held in the nursery for subsequent replacement of seedlings which died.

---

[1] Progress Report No. 2, Spacing in Douglas-fir plantations. Leo Isaac and George Meagher, 1936. Unpubl. On file at Forestry Sciences Laboratory, Olympia, Washington.

[2] Soil survey Wind River Douglas-fir spacing study on Gifford Pinchot National Forest. LeRoy C. Meyer, 1971. Unpubl. Report on file at Forestry Sciences Laboratory, Olympia, Washington.

All seedlings which died were replaced annually for the first 5 years (table 1). The first year, 36 percent of the seedlings were replaced. Many seedlings subsequently planted were to replace initial replacements, as there were spots--on ashy or shallow soil--where mortality occurred repeatedly; unfortunately, we do not have a record of these locations. Likewise, all volunteer seedlings were removed annually during the first 5 years. The stand was cleaned again in 1945--at age 21.

Table 1--Replacements during the first 5 years to maintain spacing, Wind River spacing test[1]

Year	Percent	Number	Suspected principal cause of mortality
1926	36	7200	Drought
1927	17	3300	Drought
1928	5	1000	Drought
1929	4	730	Stock too large
1930	3	630	Shoestring fungus

[1] From progress report No. 2, Spacing in Douglas-fir Plantations. Leo Isaac and George Meagher. 1936. Unpubl.

Stands have not been thinned. At all six spacings tested, the stands have now passed the ages at which they would have been thinned if they had been managed intensively. They have been maintained without thinning, however, to provide information on the long-term consequences of carrying stands at higher densities than we believe to be desirable.

Sampling and Measurements

Different sampling systems were used as the study progressed, introducing some inconsistencies in reported results. At ages 7, 12, and 17 (years from seed germination), seedling heights were measured on selected rows of trees throughout each spacing. At age 23 (1945), three 1/4-acre (0.10-ha) plots were established in each spacing, except the 12-f (3.7-m) spacing which contains a single 0.4-acre (0.16-ha) plot (fig. 1). In that year, diamete at breast height (d.b.h.) were measured on all trees on plots in the 8- through 12-ft (2.4- to 3.7-m) spacings, but on only a systematic sample of rows on plo in the 4- through 6-ft (1.2- to 1.8-m) spacings. In 1951 (age 2 plot 17 was added in the 8-ft spacing to substitute for plot 1 which was observed to be on poor

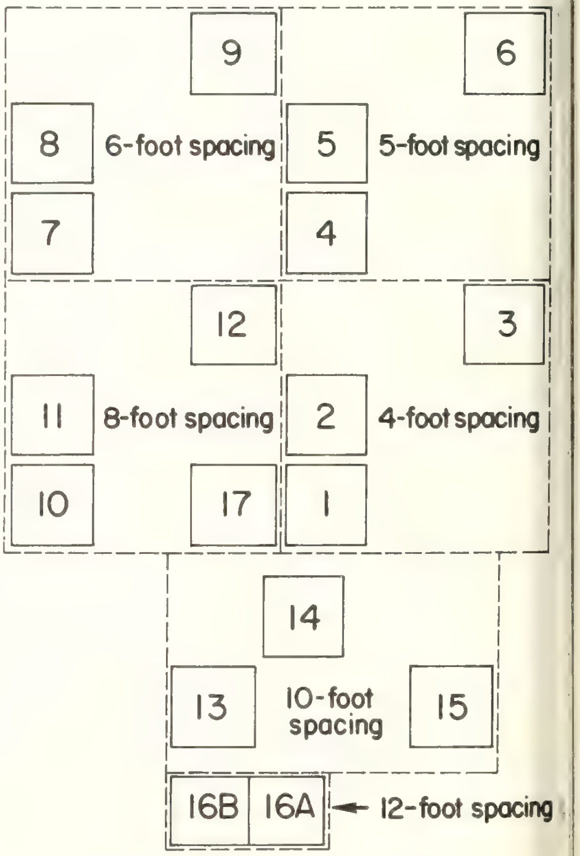


Figure 1.--Layout of Wind River Douglas-fir spacing trial (Plot 17 was added in 1951).

quality site. No measurements were made on plot 12 between 1951 and 1970; however, measurements were made again in 1970 and 1975.

Since age 29, diameters of all trees on plots (except plot 12) have been measured at approximately 5-year intervals.[3] Heights have been measured on varying numbers of trees distributed across the entire d.b.h. range; the minimum number of trees measured for height in any year has been 10 per plot. At ages 48 and 53, to assure a well-distributed sample, we gridded each plot into 16 squares and measured the height of the largest tree in each square. Measurements on all previous sample trees were also repeated to fill-out the distribution across the d.b.h. range.

All volumes for the period 1951-75 were recomputed by means of tarif equations (Brackett 1973). Cubic volumes (CVTS) of all trees measured for height were computed using the equation derived by Bruce and DeMars (1974), and tarifs were computed therefrom; these individual tree tarifs were averaged for each plot. Total and merchantable volumes of each tree were computed by d.b.h. and tarif, summed to give volumes per plot, and expanded to volumes per acre.

Because of the recomputed volumes and some adjustments to plot size (see appendix), per-acre values for ages 29 through 43 differ slightly from those reported previously.

RESULTS AND DISCUSSION

Our primary interest is in usable volume production. To place this in proper perspective, however, I first discuss the effects of spacing on the component parts of volume--namely, number of trees , height, diameter, and basal area. For each of these, I discuss development of selected stand components, as well as the total stand. Emphasis in this report is placed on tree size and yield as of 51 years after seedlings were planted (53 years from seed) and on changes which took place during the preceding 24-year period (ages 29 to 53). Earlier data, based on different sampling systems, are not directly comparable.

For each component discussed, figures illustrate both trends with spacing and individual plot data. I have split the 12-ft spacing plot into halves for this purpose. In figures where individual plots are represented by bars, these bars are always shown in the same order--decreasing top height within spacing--to facilitate comparisons. Trend curves illustrate what I believe to be reasonable approximations of effects of *spacing*, in the absence of other sources of variation. The fitting of these curves is discussed in the appendix.

Number of Trees

Number planted

Theoretical numbers of trees planted in 1925 ranged from 2,722 to 302 per acre (6,725 to 745/ha), at spacings of 4 through 12 ft (fig. 2). Stem maps reveal that actual numbers planted were very close to these theoretical numbers; the greatest disparity was on one 8-ft-spaced plot, where the number planted was 96 percent of the theoretical number.

---

[3] Plots were measured in 1951, 1956, 1960, 1965, 1970, and 1975. Number of growing seasons between measurements varied from 3.7 to 5.2.

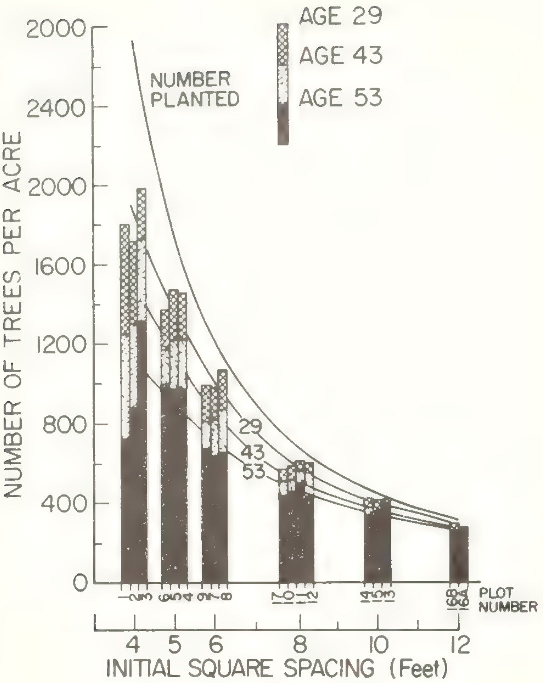


Figure 2.--Number of trees per acre, by age (clear space on bar for plot 12 indicates missing data).

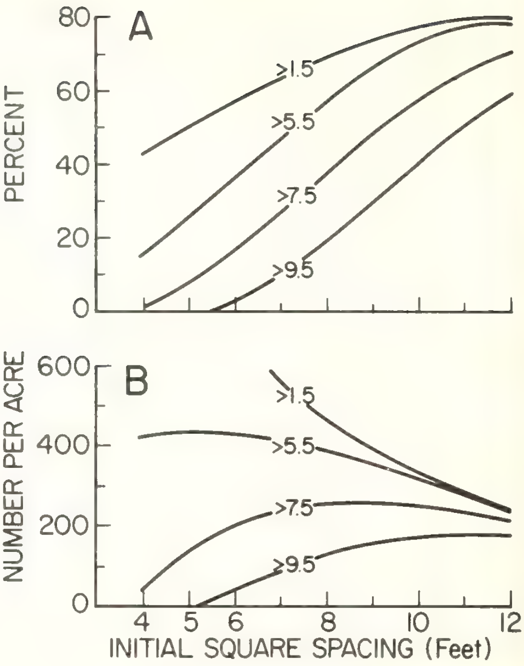


Figure 3.--Number of trees larger than specified d.b.h. at age 53: A, Percent of number planted; B, number per acre.

Number at age 53

Total stand

Fifty-one years after the trees were planted (53 years from seed), number of live trees ranged from about 1,080 to 240 per acre (2,670 to 595/ha)--or about 40 to 80 percent of the number planted (figs. 2 and 3). A very wide disparity has developed at the 4-ft (1.2-m) spacing, whereas at other spacings, numbers of trees are quite consistent among plots.

Merchantable trees

Effect of spacing on number of merchantable trees depends, of course, on the merchantability standard. By all standards, however, the number of merchantable trees expressed as a percent of the number of trees planted increases with increased spacing (fig. 3A). At 4-foot (1.2-m) spacing, about 15 percent of the trees planted were larger than 5.5 inches (14 cm) at age 53; less than 3 percent were larger than 7.5 inches (19 cm), and none were as large as 9.5 inches (24 cm). At 12-ft (3.7-m) spacing, corresponding percentages are about 78, 71, and 59.

Corresponding numbers of trees per acre are shown in figure 3B. Number of trees having a d.b.h. larger than 5.5 in (14 cm) is similar for spacings of 4 through 6 feet (1.2 to 1.8 m), averaging about 425 per acre (1,050/ha). At spacings wider than 6 feet, the number of trees larger than 5.5 inches declines with increased spacing--to about 240 per acre (595/ha) at 12-ft (3.7-m) spacing. Number of trees having a d.b.h. larger than 7.5 inches (19 cm) peaks at 8- to 10-ft (2.4- to 3.0-m) spacing--at about 260 trees per acre (640/ha). The number having a d.b.h. larger than 9.5 in (24 cm) peaks at 10- to 12-ft (3.0- to 3.7-m) spacing--at about 180 trees per acre (445/ha).

Current guidelines for precommercial thinning (Reukema 1975) assume that all trees left at 10- and 12-ft spacings would attain a d.b.h. of at least 5.5 in (14 cm). That such was not the case in these plantations is a reflection of a combination of planting procedures, microsite, genotype, and damage. When desired spacing is attained through precommercial thinning, as opposed to planting, slow-growing and defective trees are removed and their better neighbors and trees bordering openings are favored.

Dominant and codominant trees

Although crown classification is very subjective, it provides additional indicators of trends and within-spacing variation. The latter are closely related to variations in yield.

There appears to be a linear relationship between initial spacing and the percent of all trees planted which were classed as dominant or codominant at age 53 (fig. 4A). This classification includes about 65 percent of all trees planted at 12-ft (3.7-m) spacing, whereas it includes only about 20 percent of those planted at 4-ft (1.2-m) spacing. Corresponding numbers of dominant and codominant trees per acre decreases curvilinearly with spacing (fig. 4B). This number ranges from about 570 trees per acre (1,410/ha) at 4-ft (1.2-m) spacing to 200 trees per acre (495/ha) at 12-ft (3.7-m) spacing.

Mortality

By age 29, stands had lost from about 30 to 850 trees per acre (75 to 2,100/ha) at spacings of 12 and 4 feet (3.7 and 1.2 m), respectively (fig. 2 table 2). At all but the closest spacing, fewer than 15 percent of the trees had died; this early mortality was very irregular, and due to factors not associated with spacing. Only at the 4-ft (1.2-m) spacing, had competition become a major factor contributing to mortality by age 29; at this spacing, more than 30 percent of the trees had died.

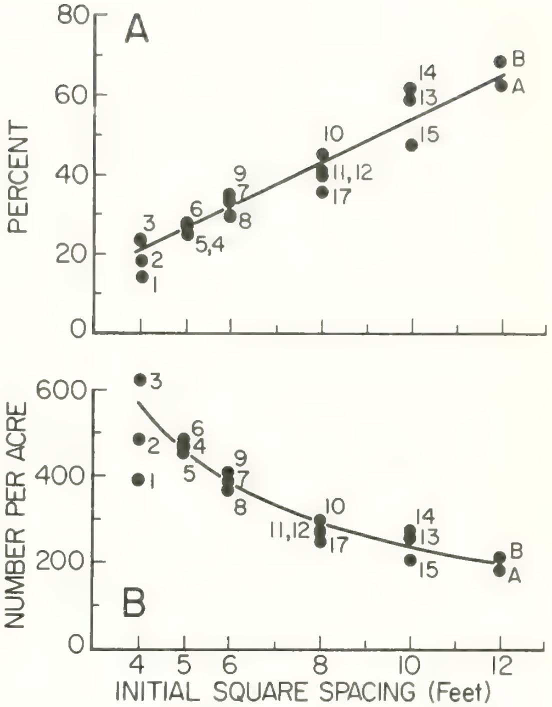


Figure 4.--Number of trees classed as dominant or codominant at age 53: A, Percent of number planted; B, number per acre.

During the 24-year period between ages 29 and 53, most mortality was related to level of competition; some was a carryover of earlier problems not related to spacing, including a little rootrot. At spacings of 4 through 6 feet (1.2 to 1.8 m), about 30 percent of the original number of trees died during this period (table 2). At spacings wider than 6 feet (1.8 m), the

Table 2--Distribution of mortality, by spacing[1] and age

Spacing (feet)	Age							Total
	7-29	29-34	34-38	38-43	43-48	48-53	29-53	
			Number of dead trees per acre					
4	850	142	55	217	286	167	867	1,717
5	256	96	44	125	142	86	493	749
6	176	31	18	134	113	61	357	533
8	85	16	7	44	47	8	122	207
10	31	4	7	30	10	7	58	89
12	31	2	3	14	9	0	28	59
			Percent of original number planted					
4	31.5	5.3	2.0	8.0	10.6	6.2	32.2	63.7
5	14.9	5.6	2.6	7.3	8.3	5.0	28.7	43.6
6	14.8	2.6	1.5	11.2	9.5	5.1	29.9	44.7
8	12.6	2.4	1.0	6.5	7.0	1.2	18.2	30.8
10	7.1	.9	1.6	6.9	2.3	1.6	13.3	20.4
12	10.3	.7	1.0	4.7	3.0	0	9.4	19.7

[1]Average of all plots within each spacing.

percent lost declined with increasing spacing--to less than 10 percent at 12-ft (3.7-m) spacing.

At close spacings, much of the density-related mortality was directly caused by snow and ice damage, which affected groups of trees and created openings in the crown canopy; at wider spacings, only scattered individual trees died (fig. 5). Among trees larger than 5.5 in (14 cm) in d.b.h., there has been relatively little mortality. On the average, only 18 such trees per acre (44/ha) have died; the distribution of these trees has been very erratic, with spacing having no clear effect. The impact of this mortality on growth and yield will be discussed later.

Height and Site Quality

Height at age 53

Average height of the 100 largest trees per acre (250/ha), as well as the averages for all trees in the stand and for other stand components, increases with increased spacing (fig. 6). Average heights of all components except the 40 tallest per acre (100/ha) were estimated by expressing height as a function of d.b.h., for each plot.

Total stand and merchantable trees

Average height of all trees in the stand ranged from less than 50 feet (15 m) at 4-ft (1.2-m) spacing to nearly 90 feet (27 m) at 12-ft (3.7-m) spacing. Average height of trees larger than 5.5 inches (14 cm) in d.b.h. ranged from about 55 to 90 ft (17 to 27 m).

The 100 largest trees per acre

The trend over spacing for the 100 largest (d.b.h.) trees per acre (250/ha) appears to nearly parallel the trend for all trees in the stand. Average height of these 100 largest trees per acre ranges from about 60 feet (18 m) at 4-ft spacing to 95 feet (29 m) at 12-ft spacing.

The 40 tallest trees per acre

To avoid the impact of errors in estimating height as a function of d.b.h., I computed the arithmetic averages of the 10 tallest

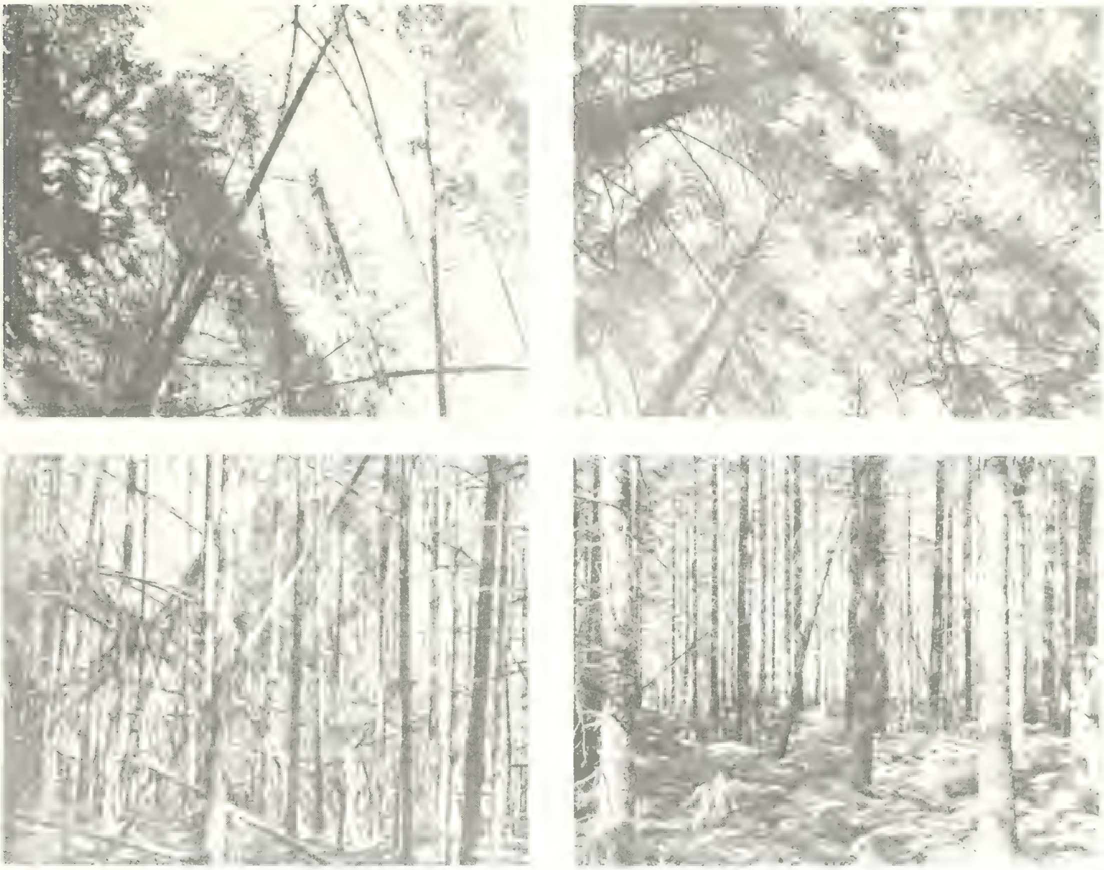


Figure 5.--Clumped damage was a common occurrence in the 4-foot (1.2-m) spacing (left), whereas there was little damage in the 10-foot (3.0-m) spacing (right). The stands pictured are both close to the boundary between the 4- and 10-foot spacings.

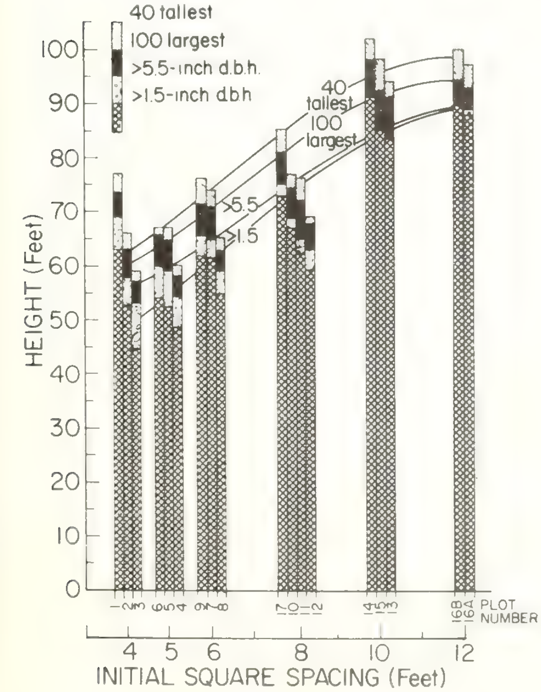


Figure 6.--Average height at age 53, by stand component.

trees from among the 16 largest (by d.b.h.) well-distributed trees per plot. I consider these equivalent to the 40 tallest trees per acre (100/ha). There is a very clear trend of increasing height with increased spacing, with average height of these 40 tallest trees per acre (100/ha) ranging from about 62 ft (19 m) to 99 ft (30 m) at spacings of 4 and 12 ft (1.2 and 3.7 m).

Height growth

Most of the effect of spacing on height growth has occurred since about age 20. By age 29, the 100 largest trees per acre (250/ha) were about 8 feet, or 18 percent, taller at 12-ft than at 4-ft (3.2 vs. 1.2 m) spacing--51 vs. 43 feet (15.5 vs. 13.1 m) (fig. 7). During the 24-year period between ages 29 and 53, the 100 largest trees per acre grew an average of 43 feet (13.1 m) at 10- and 12-ft spacings, but only 17 feet (5.1 m) at 4-ft spacing.

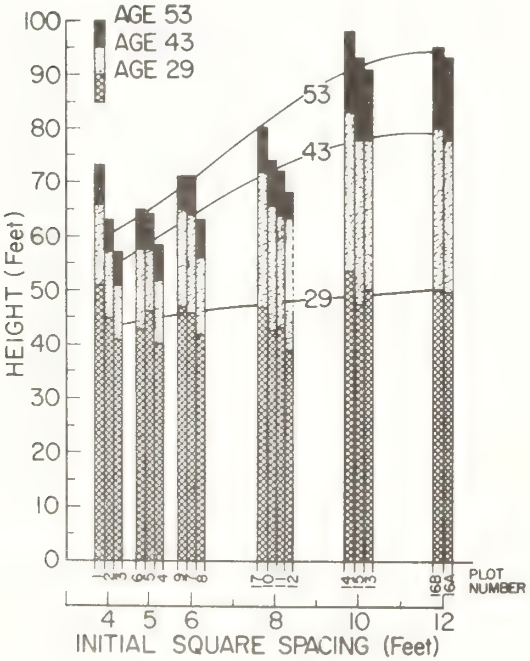


Figure 7.--Cumulated growth in height of the 100 largest trees per acre, by period (clear space on bar for plot 12 indicates missing data).

Effect of spacing vs. site quality

Current heights indicate (1) substantial within-spacing variation in site index and (2) a strong trend of increased site index with increased spacing. The question arises as to whether the latter is really an effect of spacing or of true differences in site quality. Several pieces of evidence bear on this question.

There is considerable evidence dating back to early measurements that the block planted at 8-ft spacing is generally on poorer quality site than blocks planted at other spacings. This is illustrated by the relative number of trees which had attained some specific minimum height; the 8-ft spacing had many fewer such trees than did other spacings (table 3) Even though current heights on plots at 8-ft spacing (except plot 17) fall out of line with the trend, height growth between ages 29 and 53 was greater on all four of these plots than on any plot at closer spacing.

The best plots at 4- and 10-ft spacing (plots 1 and 14) are in close proximity to each other (fig. 1). These plots are substantially superior in height and yield to other plots in their respective spacings, indicating that this portion of the area is better than the average quality site. Yet heights on this best plot at 4-ft spacing are much shorter than on any plot at 10-ft spacing. There is some evidence from soil characteristics that the 10- and 12-ft spacings may be on slightly better than the average site quality; however, there is nothing to suggest real site differences of anywhere near the magnitude indicated by current heights.

Table 3--Relationship between spacing and tree height (acre basis); trees taller than specified height at ages 12 and 17; Wind River spacing test

Spacing (feet)	Age 12, trees >9.5 feet tall		Age 17, trees >17.5 feet tall	
	Number of trees	Percent of total	Number of trees	Percent of total
4	463	17	426	16
5	364	21	317	18
6	256	21	235	19
8	46	7	65	10
10	111	25	168	39
12	85	28	139	46

It is also clearly evident from the exterior row of trees planted at close spacings that amount of available growing space does have an effect on height of even the tallest trees. The planted trees bordering the surrounding natural stand are substantially taller than trees in the interior of the closely spaced plantation.

Therefore, differences in site index among spacings are attributed primarily to effects of differing intensity of competition on height growth. Height growth in the wider spacings has improved relative to "normal" stands, whereas that in the closer spacings has diminished.

An accumulating body of evidence suggests that better height growth at wide spacings than at close spacings may be common on poor sites. On the other hand, spacing apparently has little effect on height growth on good sites, except at extremely dense spacings. Most of the literature pertaining to this subject has been reviewed by Sjolte-Jorgensen (1967) and Evert (1971, 1973). Some unpublished evidence[4] also supports the concept of better height growth at wide spacings on poor sites. It is reasonable that spacing should have more effect on poor sites because--for a given spacing--the poorer the site, the longer the time to crown closure (Reukema & Bruce 1977).

Diameter

Diameter at age 53

Average d.b.h.[5] of the total stand, of merchantable trees (larger than 5.5 inches (14 cm), and of the 100 largest trees per acre (250/ha) all increase with increased spacing (fig. 8).

Total stand

Virtually all live trees have a d.b.h. of at least 1.5 inches (4 cm). Average d.b.h. of these trees at age 53 ranged from about 5.1 inches (13 cm) at 4-ft (1.2-m) spacing to 11.3 inches (28.7 cm) at 12-ft (3.7-m) spacing. Distributions around these averages are tabulated in the appendix.

Merchantable trees

Average d.b.h. of trees larger than 5.5 inches (14 cm) ranged from about 6.5 inches (16.5 cm)

---

[4] On file at Forestry Sciences Laboratory, Olympia, Washington.

[5] Average d.b.h. refers to diameter at breast height of the tree of mean basal area.

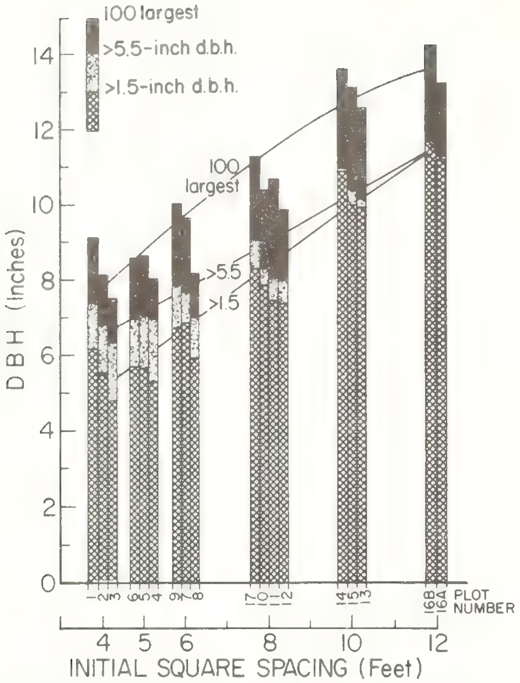


Figure 8.--Average d.b.h. at age 53, by stand component.

at 4-ft spacing to 11.4 inches (29 cm) at 12-ft spacing. At wide spacings, nearly all trees are larger than 5.5 inches. At 4- and 5-ft (1.2- and 1.5-m) spacings, fewer than half of all live trees are larger than 5.5 inches in d.b.h.

The 100 largest trees per acre

Average d.b.h. at age 53 of the 100 largest trees per acre (250/ha) ranged from about 7.8 inches (19.8 cm) at 4-ft (1.2-m) spacing to 13.6 inches (34.5 cm) at 12-ft (3.7-m) spacing. The trend over spacing for these largest trees nearly parallels that for all trees in the stand. The substantial variation among plots *within spacing* generally parallels variation in height.

Diameter growth

The 100 largest trees per acre

During the 24-yr period between ages 29 and 53, diameter growth on the 100 largest trees per acre (250 per hectare) was about twice as much at 12-ft spacing as at 4-ft spacing (fig. 9); periodic annual increments (p.a.i.) were 0.20 vs. 0.10 inch (0.50 vs. 0.24 cm). During the most recent 10 years of this period, corresponding rates of diameter growth were 0.15 vs. 0.08 inch (0.38 vs. 0.20 cm) per year.

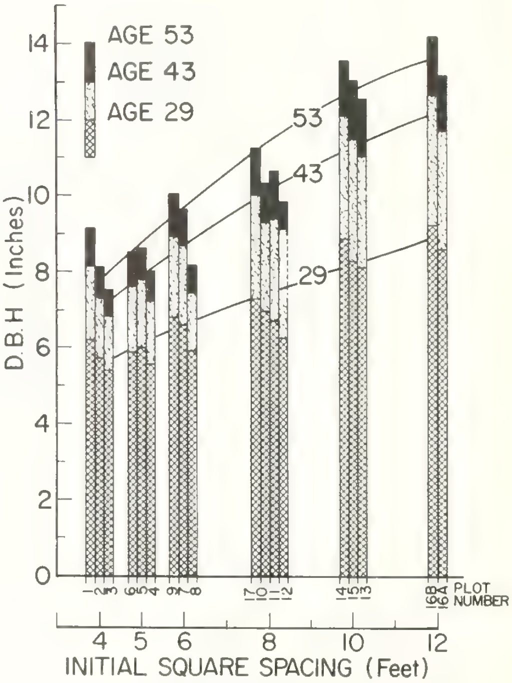


Figure 9.--Cumulated growth in d.b.h. of the 100 largest trees per acre, by age (clear space on bar for plot 12 indicates missing data).

Other trees

Growth as a function of tree diameter also has varied by spacing in recent years, contrary to previous trends (Reukema 1970). For trees of a given d.b.h. at the start of the period, those at close spacings have grown more during the past 10 years than those at wide spacings. Trees of a given size are in a more favorable crown position at successively closer spacings; i.e., we are comparing dominants at close spacing with intermediates at wide spacings.

Very few additional trees reached the minimum merchantable d.b.h. of 5.6 inches (14 cm) during the most recent 5-yr period. A few more will, but most submerchantable trees are growing very slowly, if at all. At the closest spacings, a few of these submerchantable trees are codominants and will grow to merchantable size; even a few intermediates may. At 8-ft (2.4-m) and wider spacings, the few submerchantable trees which remain in the stands are mostly in the suppressed crown class; they have essentially ceased growing.

Basal Area

Basal area at age 53

Basal area of live trees (i.e., net basal area) and gross basal area produced (including basal area of trees which have died) are both quite variable and only loosely associated with spacing. Basal area of merchantable trees and, especially, the 100 largest trees per acre are much more closely related to spacing (fig. 10). Variation, among plots *within spacing*, in the basal area of the 100 largest trees per acre (250/ha) closely parallels variation in height; it undoubtedly reflects variation in site quality. The much greater variation in basal area of the total stand reflects, in addition, differences in fullness and uniformity of stocking.

Total stand

Gross basal area production to age 53 still tends to decrease with increased spacing; from about 210 ft^2 per acre (48 m^2/ha) at 4-ft (1.2-m) spacing to 190 ft^2 per acre (44 m^2/ha) at 10-ft (3.0-m) spacing, and 175 ft^2 per acre (40 m^2/ha) at 12-ft (3.7-m) spacing. Basal area of live trees tends to increase as spacing increases; from about 160 ft^2 per acre (37 m^2/ha) at 4-ft spacing to 180 ft^2 per acre (42 m^2/ha) at 10-ft spacing.

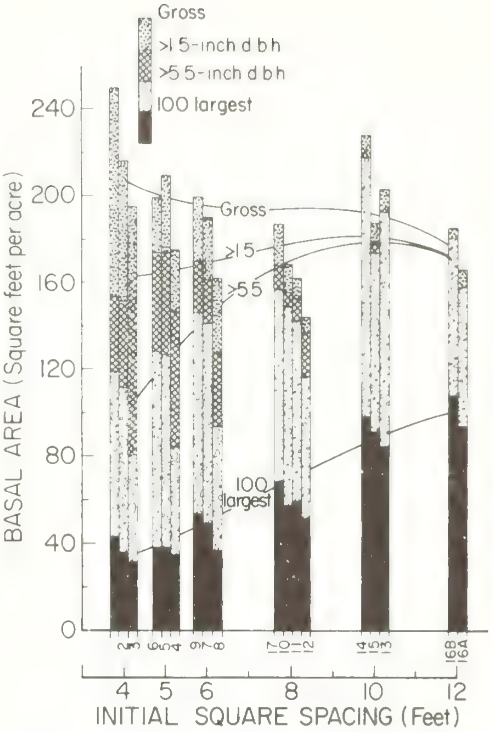


Figure 10.--Basal area per acre at age 53, by stand component.

Gross basal area production at close spacings would be greater than indicated *if* sizeable areas had not been lost to production because of the clumpwise distribution of damage and mortality. Smith[6] has shown much greater growth in *fully stocked* portions of stands planted at close spacings.

---

[6] J. Harry G. Smith. Maximal annual basal area growth at various spacings estimated by tree ring analyses. Paper presented at Pacific Division, AAAS 59th Annual Meeting (Seattle, Wash.), June 1978.

Merchantable trees

Basal area of trees larger than 5.5 inches (14 cm) clearly increases with increased spacing--up to 10-ft (3.0-m) spacing; via the trend curve, it ranges from about 95 ft^2 per acre (22 m^2/ha) at 4-ft (1.2-m) spacing to 180 ft^2 per acre (41 m^2/ha) at 10-ft (3.0-m) spacing. Basal area of these merchantable trees appears to be a little less at 12-ft (3.7-m) than at 10-ft spacing, although the basal area in such trees is greater on the best 12-ft-spacing plot than on the poorest 10-ft-spacing plot. Trees larger than 5.5 inches (14 cm) in d.b.h. account for less than 75 percent of the total-stand basal area at close spacings, whereas they account for nearly all of the total-stand basal area at wide spacings.

The 100 Largest trees per acre

Basal area of the 100 largest trees per acre (250/ha) obviously increases with increased spacing--from about 35 to 100 ft^2 per acre (8 to 23 m^2/ha) at spacings of 4 and 12 ft (1.2 and 3.7 m), respectively. The trend appears to be only slightly curvilinear; basal area of these 100 largest trees per acre is nearly proportional to spacing.

Basal area mortality

The difference between gross basal area production and basal area of the total live stand is mortality. This is quite closely related to spacing. During the period between ages 29 and 53, about 50 ft^2 per acre (11.5 m^2/ha) was lost at the 4-ft (1.2-m) spacing, whereas less than 5 ft^2 per acre (1 m^2/ha) was lost at the 12-ft (3.7-m) spacing. Corresponding percentages of total production lost to mortality are about 22 and 3 percent, at 4- and 12-ft (1.2- and 3.7-m) spacings.

Basal area growth

To provide a more complete picture of effect of spacing on growth, I have examined not only total-stand growth but also the contribution of the 100 largest trees per acre (250/ha) to this total.

Total stand

Gross basal area growth during the period between ages 29 and 53 averaged 27 percent greater at the two widest spacings than at the two closest. Thus, the effect of spacing on cumulated gross basal area production--i.e., reduced production with increased spacing--has diminished with increasing age (fig. 11). Basal

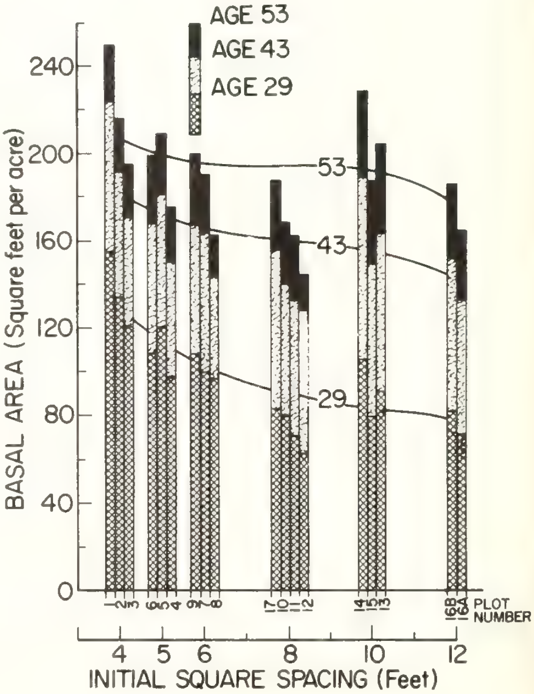


Figure 11.--Cumulated growth in basal area per acre, by period (clear space on bar for plot 12 indicates missing data).

area growth for the total stand has clearly been greatest at 10-ft (3.2-m) spacing (fig. 12A); it has been greater even on the poorest of the 10-ft-spacing plots than on any plot at either closer or wider spacing.

The 100 largest trees per acre

Growth per tree increases with increased spacing, as indicated by growth of the 100 largest trees per acre (fig. 12B). The relationship appears to be essentially linear for spacings of 4- through 10-ft (1.2- to 3.0-m); however, it appears curvilinear when the 12-ft (3.7-m) spacing is included. The ratio of growth of these 100 largest trees to growth of the total stand is essentially linearly related to spacing (fig. 13). Variations around this trend indicate, primarily, variations in stocking; the greater the ratio for a given spacing, the less complete the stocking. The 100 largest trees per acre (250/ha) accounted for less than 25 percent of the total-stand growth at the closest spacing and for about 60 percent of it at the widest spacing. Their contribution to growth is essentially the same as their contribution to growing stock.

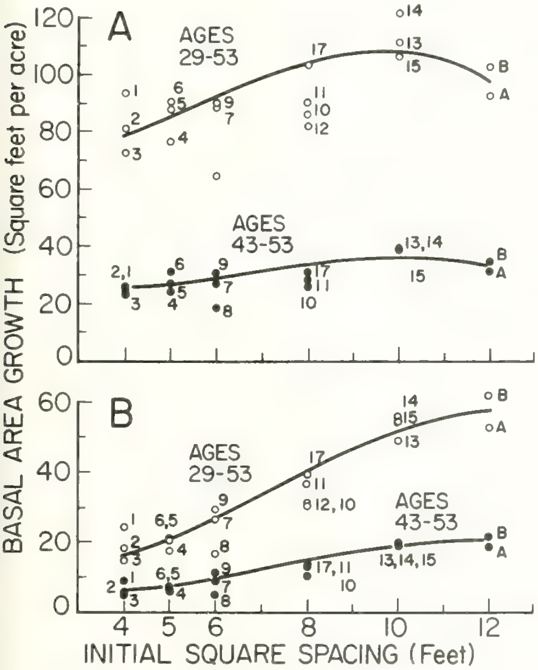


Figure 12.--Basal area growth per acre between ages 29-53 and 43-53: A, Total stand; B, The 100 largest trees.

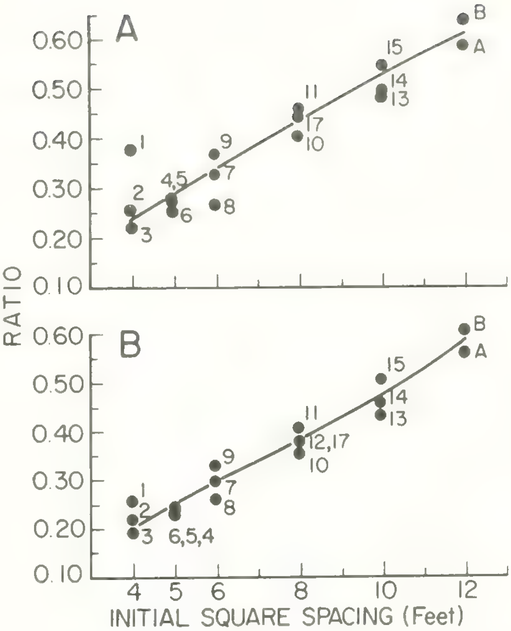


Figure 13.--Basal area growth of the 100 largest trees relative to growth of the total stand: A, Ages 43-53; B, Ages 29-53.

Cubic Volume

Total cubic volume at age 53

I first examined effect of spacing on total-stem volume of both (1) all trees in the stand and (2) selected components of the stand. I then examined effect of spacing on the merchantable (or usable) portion of this volume.

Contrary to trends of basal area with spacing, volume of live trees and gross volume produced are both *greater* at wide spacings than at close spacings. This is due mostly to the fact that trees are taller at wider spacings. Trends for trees larger than 5.5-inches (14-cm) d.b.h. and for the 100 largest trees per acre (250/ha) are very similar to those for basal area. Likewise, variation among plots within spacing is quite similar to that for basal area (fig. 14).

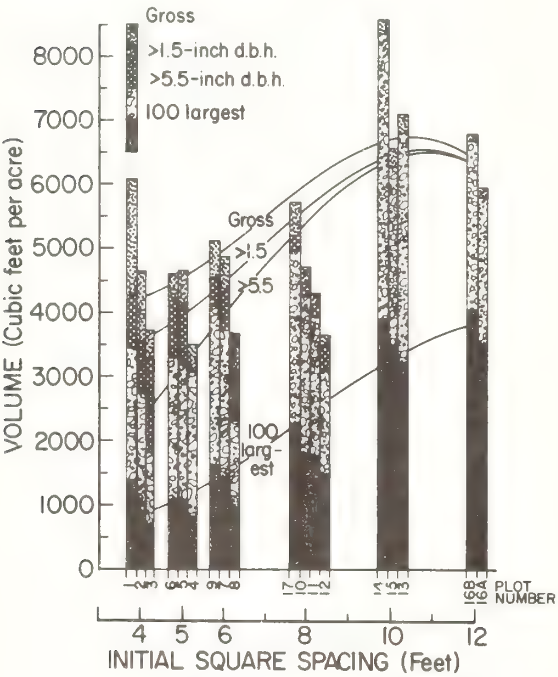


Figure 14.--Cubic volume per acre at age 53, by stand component.

Total stand

Cubic volume produced is clearly greater at 10- and 12-ft (3.0- and 3.7-m) spacings than at closer spacings. Gross volumes via the trend curve range from about 4,235 to 6,685 ft^3 per acre (296 to 468 m^3/ha) at 4- and 10-ft (1.2- and 3.0-m) spacings, respectively. Corresponding net volume volumes (live trees) range from about 3,545 to 6,425 ft^3 per acre (248 to 450 m^3/ha).

Merchantable trees

Cubic volume of trees larger than 5.5-inches (14-cm) d.b.h. ranges from about 2,340 ft^3 per acre (164 m^3/ha) at 4-ft (1.2-m) spacing to 6,360 ft^3 per acre (445 m^3/ha) at 10-ft (3.0-m) spacing. Volume in trees larger than 5.5 inches accounts for nearly all of the total stand volume at 10- and 12-ft (3.0- and 3.7-m) spacings; at the 4-ft (1.2-m) spacing, volume in trees larger than 5.5 inches accounts for only about two-thirds of the total volume.

The 100 largest trees per acre

Cubic volume of the 100 larges trees per acre (250/ha) ranges from about 850 ft^3 per acre (59 m^3/ha) at 4-ft (1.2-m) spacing to 3,840 ft^3 per acre (269 m^3/ha) at 12-foot spacing. The trend is only slightly curvilinear. These trees account for about 25 percent of total volume at 4-ft (1.2-m) spacing and for about 60 percent of it at 12-ft (3.7-m) spacing.

Cubic volume mortality

Mortality--the difference between gross volume production and volume of the total live stand--has been less at wide spacing than at close spacings, but varies widely within spacing (fig. 14). As defined by the trend curve, the volume lost to mortality during the 24-year period between ages 29 and 53 ranged from about 690 ft^3 per acre (48 m^3/ha) at 4-ft (1.2-m) spacing to 90 ft^3 per acre (6 m^3/ha) at 12-ft (3.7-m) spacing.

At the 4- and 8-ft (1.2- and
4-m) spacings, the volume lost
mortality appears to be re-
ted to stocking level; the
eater the stocking level, the
eater the mortality. At other
acings, however, no such rela-
onship between stocking level
d mortality was evident.

Cubic volume growth

Gross cubic volume growth dur-
g the period between ages 29
d 53 averaged twice as much at
e two widest spacings as at the
o closest spacings. Therefore,
e effect of spacing on gross
lume production has increased
th increasing stand age
ig. 15).

During both the total 24-year
riod and the most recent 10
ars, growth was clearly greater
10- and 12-ft (3.0- and 3.7-m)
acings than at closer spacings
ig. 16A). Growth was apparently
little less at the 12-ft than
the 10-ft (3.7-m vs. 3.0-m)
acing; however, growth on the
st 12-ft-spaced plot was virtu-
ly identical to growth on the
o poorer 10-ft-spaced plots.
a trend curves, growth between
es 29 and 53 ranged from about
370 to 5,130 ft^3 per acre (166
359 m^3/ha) at spacings of 4 and
ft (1.2 and 3.0 m), respec-
vely. Thus, annual growth dur-
g the 24-yr period averaged 99
214 ft^3 per acre (6.9 to
.0 m^3/ha).

The 100 largest trees per acre

The trend of growth of the
0 largest trees per acre
50/ha) relative to spacing is
shaped (fig. 16B). The rate
growth increases rapidly as
acing is increased from 4 to
ft (1.2 to 3.0 m). The rate
increase then levels-off
mewhat with yet wider spacing--
it must, eventually.

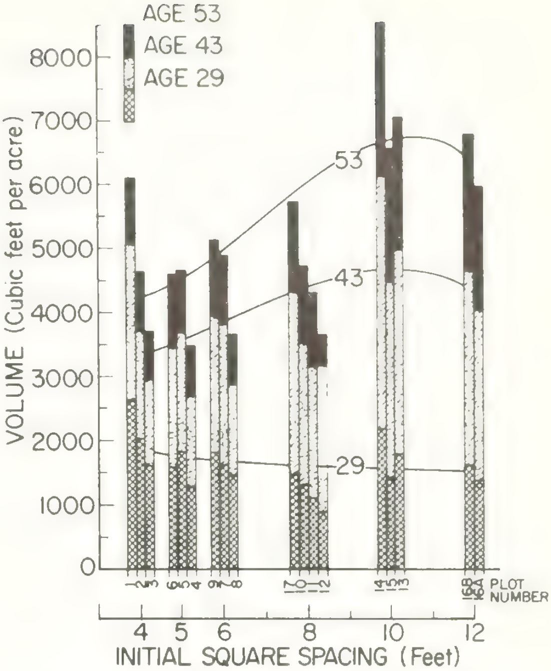


Figure 15.--Cumulated growth in cubic volume per acre, by period (clear space on bar for plot 12 indicates missing data).

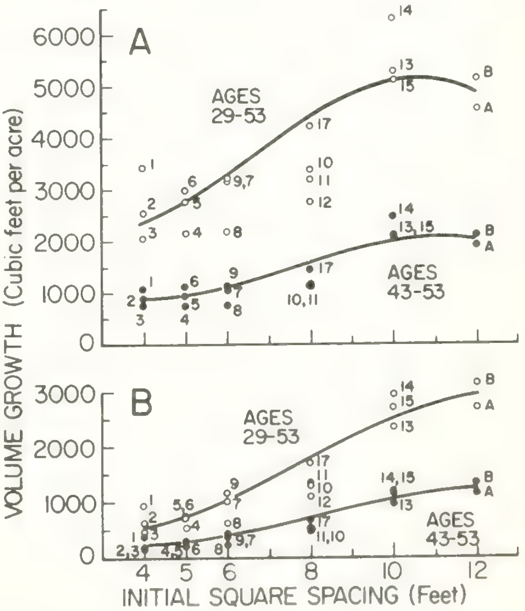


Figure 16.--Cubic volume growth per acre between ages 29-53 and 43-53: A, Total stand; B, The 100 largest trees.

The ratio of growth of these 100 largest trees to growth of the total stand appears to be linearly related to spacing, as for basal area growth. Growth of these 100 largest trees per acre (250/ha) accounted for about 25 percent of the total-stand growth at 4- and 5-ft (1.2- and 1.5-m) spacings to 60 percent of total-stand growth at the 12-ft (3.7-m) spacing. Thus, as for basal area, the contribution of these 100 largest trees per acre (250/ha) to growth has been nearly proportional to their current contribution to growing stock.

Growth relative to growing space

Plotting growth relative to growing space (S^2), rather than to spacing (S), perhaps gives a little clearer picture of relationships (fig. 17). This shows that volume growth--between ages 29 and 53--of the 100 largest trees per acre (250/ha) was nearly proportional to growing space (S^2) for spacings of 4 through 10 ft (1.2 to 3.0 m). The slope of this curve declines sharply, however, as spacing is increased from 10 to 12 ft (3.0 to 3.7 m).

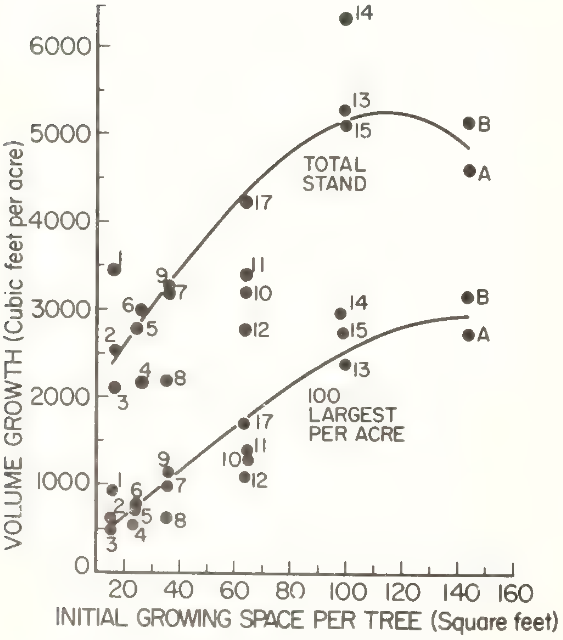


Figure 17.--Cubic volume growth per acre of the total stand and the 100 largest trees, ages 29-53.

Corresponding growth of the total stand is nearly linearly related to growing space (S^2) through about 8-ft spacing. The rate of increase declines as spacing increases from 8 to 10 f The sharp decline in growth rate thereafter is associated with th growth trend for the 100 largest trees per acre; with spacing greater than about 10 ft, growth of individual trees has not been enough greater to offset the impact on total growth of having fewer trees than at 10-ft spacin

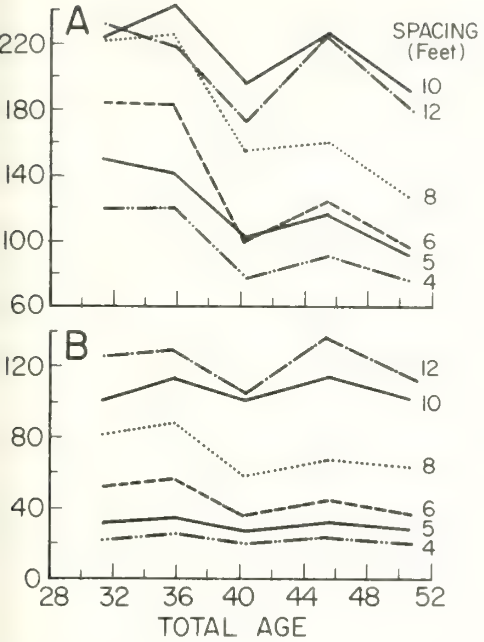
Trends and culmination of growth

Periodic annual growth (p.a.i of both total stands and the 100 largest trees per acre (250/ha), has been very erratic (fig. 18).[7] As expected, p.a.i. of the total stand tended to decrease as age increased. P.a.i. of the 100 largest trees per acre generally tended to remain nearly constant as age increased from 29 to 53; trends for 6- and 8-ft (1.8- and 2.4-m) spacings appear to deviat from this generality.

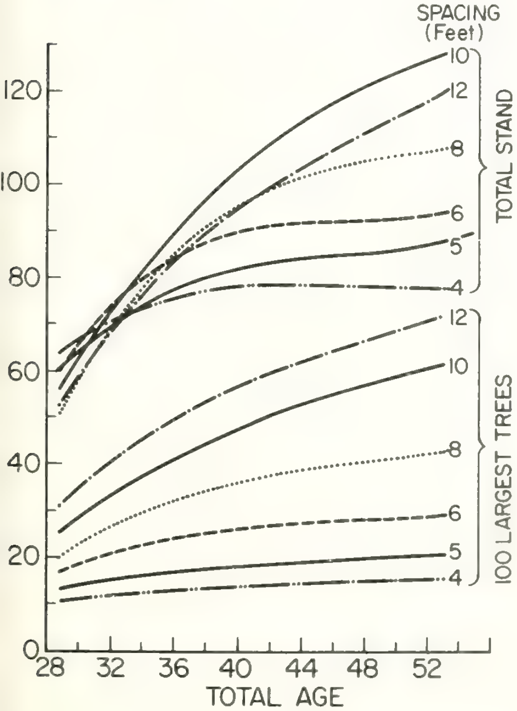
At close spacings, gross mean annual increment (m.a.i.) of the total stand apparently culminate at about age 50, or is currently very close to culmination; at wide spacings, m.a.i. is still far short of culmination (fig. 19 Likewise, at close spacings, m.a of the 100 largest trees per acr (250/ha) is near to culmination, whereas at wide spacings m.a.i. is still increasing substantiall with increasing age.

---

[7] Length of periods varied from 3.7 to 5.2 growing seasons.



gure 18.--Gross periodic annual increment (p.a.i.) in cubic volume per acre, by periods from ages 29 to 53: A, Total stand; B, The 100 largest trees.



gure 19.--Gross mean annual increment (m.a.i.) in cubic volume per acre from ages 29 to 53: Total stand and the 100 largest trees

Differences in current growth rates, and age at which m.a.i. culminates, are associated with differences in crown dimensions and vigor. At age 45, average crown length of the 100 largest trees per acre at 4-ft spacing was only about 20 ft (6 m); that a 12-ft spacing was about 40 ft (12 m) (Curtis and Reukema 1970). Corresponding crown widths were about 12 ft (3.7 m) and 18 ft (5.5 m).

Impact of mortality on growth and yield

Since most trees which have died have been of submerchantable size, there has been very little *direct* effect on usable production. Some of these submerchantable trees, however, would have otherwise reached merchantable size, especially those at close spacings which were dominant or codominant trees when damaged. Therefore, the clumpwise mortality pattern at close spacings has been responsible for an *indirect* loss in usable production. The close spacings have more dominant and codominant trees, but these trees occupy the area much less efficiently than at wider spacings. Furthermore, in the close spacings, trees surrounding the openings have less vigorous crowns than those in wide spacings, so have been less able to respond to release received from these natural openings.

Merchantable volume at age 53

Up to now, I have considered only the effect of spacing on cubic volume of the *total* stem (CVTS). I have shown how much of this *total* is included in selected components of the stand. The effect of spacing on the *usable* part of this volume depends on merchantability standards; the larger the desired diameter, the greater the advantage of wide spacing (fig. 20).

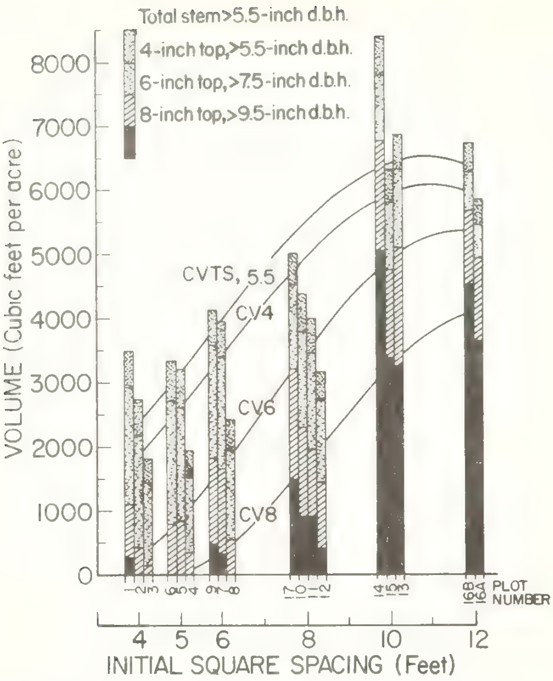


Figure 20.--Merchantable cubic volume per acre at age 53, by merchantability standard.

For the following discussion, merchantable volume--in trees larger than a specified d.b.h.--is the total volume of the portion of the stem included between the stump and the specified minimum top diameter. In all cases, the stump height is 1 percent of total tree height or 1 ft (30 cm), whichever is less.

If minimum top diameter is 4 inches (10 cm), merchantable volume (CV4) in trees larger than 5.5-inch (14-cm) d.b.h. ranges from less than 2,000 ft^3 per acre (140 m^3/ha) at 4-ft (1.2-m) spacing to about 6,000 ft^3 per acre (420 m^3/ha) at 10- and 12-foot (3.0- and 3.7-m) spacings. Thus, on the average it is about 500 ft^3 per acre (35 m^3/ha) less than the total stem volume of those same trees.

If stems can be utilized only to a minimum top diameter of 6 in (15 cm), merchantable volume (CV6) in trees larger than 7.5-inch (19-cm) d.b.h. ranges from less than 300 ft^3 per acre (20 m^3/ha) at 4-ft spacing to about 5,300 ft^3 per acre (370 m^3/ha) at 12-f spacing. If minimum top diamete is 8 inches (20 cm), then merchantable volume (CV8) in trees larger than 9.5-inch (24-cm) d.b.h. ranges from zero at 4-ft spacing to over 4,000 ft^3 per acre (280 m^3/ha) at 12-ft spacin

Advantages of 12-ft spacing relative to 10-ft spacing are obvious. Production of usable volume has been as great or *greater* at the 12-ft as at the 10-ft spacing, depending upon merchantability standards. Furthermore, there need be littl concern about excessive size of branches at the wide spacings. Branch size at the 12-foot spacing is currently quite acceptabl Crowns closed many years ago and have lifted well.

CONCLUSIONS AND MANAGEMENT IMPLICATION

Trees planted at wide spacing have attained a much larger diameter and height and have produce much more merchantable volume than have those planted at close spacings. Differences, in favor of wider spacings, have continue to increase during the past 10 years.

Height and diameter growth of even the largest trees has been strongly affected by spacing. The 100 largest trees per acre are currently (age 53) nearly 60 percent taller and 75 percent larger in diameter at 12-ft than at 4-ft spacing. At 12-ft spacing, these trees now average 94 ft (28.6 m) tall and 13.6 inch (34.5 cm) in d.b.h.

Total volume production has been greatest at the 10-ft spacin Growth rate of individual trees is greater at 12-ft than at 10-ft spacing, but not enough greater o offset the effect on total rowth of fewer trees being presnt. Production of *usable* volume, owever, has been as great or *reater* at the 12- as at the 0-ft spacing, depending on merhantability standards.

Current mean annual increment m.a.i.) of the 100 largest trees er acre at the 12-ft spacing is lmost as much as m.a.i. of *all* rees at the 4-ft spacing. urthermore, m.a.i. has culminted at close spacings, whereas t is still far short of culmintion at wide spacings. In terms f live trees, the 12-ft spacing urrently has more volume in the 00 largest trees than the 4-ft pacing has in more than 1,000 rees.

Where trees have been planted t close spacings, only a small raction of the trees reached a erchantable size; and a subtantial part of the total volume roduced was in submerchantable rees. Furthermore, these very niform stands did not self-thin ffectively. This caused growth f even the best trees in the tand to be severely retarded, nd it made the stands more suseptible to snow and ice damage hich created openings within he stand.

The apparent effects of spacng illustrated by this study re greater than those indicated n most published results of tudies elsewhere (Sjolte-orgensen 1967; Evert 1971, 1973). t appears common, however, for aximum production on low-site-uality land to be attained hrough much wider than normal pacing of trees. Results of his study are believed to be ypical of what can be expected n comparable sites. On better ites, spacing apparently has ittle effect on height growth; hus, effects of spacing on tree ize and yields are somewhat less han observed in this study.

One should use caution in drawing implications from a single study, such as this. Therefore, information derived from several studies--including this one--has been formulated into a model of stand structure and development (Reukema & Bruce 1977). Management implications may be drawn from this model.

This spacing trial clearly illustrates the potential benefits from planting trees at wider spacing, or making an early precommercial thinning to such spacing, on lands of poorer than average site quality. Proper spacing of trees depends on the tree size desired at the first commercial entry. If one plans to commercially thin when trees average about 8-inch (20-cm) d.b.h., trees should be spaced about 10 feet (3 m) apart. If one wishes to have a larger average d.b.h. at the time of the first commercial entry, trees should be spaced more widely.

The detrimental consequences of carrying too many trees is clearly illustrated by the close spacings. Conversely to the above spacing guide, stands should be thinned when trees reach the size commensurate with their spacing. Thus, if stands in this spacing trial were being managed intensively, the stand planted at 12-ft (3.7 m) spacing should have been thinned at about age 45--when trees averaged about 10-inch (25-cm) d.b.h. and 80 ft (24 m) tall. Stands planted at closer spacings should have been thinned at progressively younger ages--with smaller trees being cut. Failure to thin at the appropriate time can offset the potential benefit from early control of spacing.

LITERATURE CITED

Brackett, Michael.
1973. Notes on tarif tree volume computation. Resour. Manage. Rep. 24, 26 p. Wash. State Dep. Natur. Resour., Olympia.

Bruce, David, and Donald J. DeMars.
1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Curtis, Robert O., and Donald L. Reukema.
1970. Crown development and site estimates in a Douglas-fir plantation spacing test. For. Sci. 16(3):287-301.

Eversole, Kenneth R.
1955. Spacing tests in a Douglas-fir plantation. For. Sci. 1:14-18.

Evert, F.
1971. Spacing studies - A review. For. Manage. Inst. Infor. Rep. FMR-X-37, 95 p. Can. For. Serv., Ottawa, Ontario.

Evert, F.
1973. Annotated bibliography on initial tree spacing. For. Manage. Inst. Infor. Rep. FMR-X-50, 149 p. Can. For. Serv., Ottawa, Ontario.

Isaac, Leo A.
1937. 10 years' growth of Douglas-fir spacing-test plantations. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 23:6. Portland, Oreg.

Munger, Thornton T.
1946. The spacing in plantations. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 34:3-4. Portland, Oreg.

Reukema, Donald L.
1959. Some recent development in the Wind River Douglas-fi Plantation spacing tests. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn Note 167, 7 p. Portland, Oreg.

Reukema, Donald L.
1970. Forty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-100, 21 p. Pac. Northwest For. and Range Exp. Stn., Portland Oreg.

Reukema, Donald L.
1975. Guidelines for precommercial thinning of Douglas-fir. USDA For. Serv. Gen. Tech. Rep. PNW-30, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Reukema, Donald L., and David Bruce.
1977. Effects of thinning on yield of Douglas-fir: Concepts and some estimates obtained by simulation. USDA For. Serv. Gen. Tech. Rep. PNW-58, 36 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Sjolte-Jorgensen, J.
1967. The influence of spacing on the growth and development of coniferous plantations. *In* International review of forest research, Vol. 2, p. 43-94. Academic Press, New York.

PPENDIX

itted Curves

Trend curves illustrate what
believe to be reasonable approx-
mations of effects of *spacing*,
n the absence of other sources
f variation. Equations were
itted to selected plots to
acilitate automation in plot-
ing graphs. Most of these
elationships are represented
y third-degree curves, which
losely approximate former free-
and curves.

For this purpose, 7 of the 18
lots were excluded from influ-
ncing the shape of these curves,
ecause inclusion of all plots
ould result in unrealistic
urve shapes. Three of these
lots sample the 8-foot spacing,
hich is apparently on generally
oorer-quality site than the
verage; only the best plot in
his spacing (plot 17) falls in
ine with general trends. Others
xcluded were the best of the
lots at 4- and 10-foot spacings
plots 1 and 14), which are appar-
ntly on better-quality site than
ny other plots, and the poorest
f the plots at 5- and 6-foot
pacings (plots 4 and 8), which
re much poorer than other plots
t these spacings.

djustments for Plot Size

Because dimensions of plots--
.g., 104.36 feet for a square
uarter-acre plot--are not exact
ultiples of spacing distances,
ome plots have either more or
ewer planting spots than would
heoretically be found on that
raction of an acre. Therefore,
he expansion factor to an acre
asis has always been derived
rom an adjusted plot size (the
heoretical area initially occu-
ied by trees), rather than from
he nominal size of the plot.
Adjusted size of plots which are nominally 0.25-acre varies from 0.2296 to 0.2661 acre. Adjusted size of each half of the plot at 12-foot spacing is 0.2116 acre.

Examination of stem maps revealed some errors in the previous determination of this adjusted plot size. Therefore, some per acre values in this report have been changed, relative to those reported previously. The greatest impact is on the 12-foot spacing, where the plot is 6.7 percent larger than previously believed; thus, all per acre values for this spacing are less than previously reported.

D.b.h. Distribution

D.b.h. distributions at age 53, by spacing, are tabulated in Table 4. These are based on only the plots to which trend curves were fitted.

Table 4--D.b.h. frequency distribution 1975 (age 53)

D.b.h. class	Spacing feet					
	4	5	6	8	10	12
	- - Number of trees per acre - -					
2	67	49	24	8		
3	191	129	40	8	2	
4	244	154	68	28	8	2
5	217	162	88	45	9	3
6	237	213	98	40	24	9
7	110	131	130	60	55	14
8	23	85	94	65	26	5
9	16	39	70	72	45	31
10	4	8	22	49	61	33
11			10	40	42	33
12			4	12	47	43
13			4	12	7	25
14				4	9	29
15					9	4
16					0	6
17					4	4
Total	1,109	970	652	443	348	241

Reukema, Donald L.
1979. Fifty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-253, 21 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A 51-yr record of observations in stands planted at six spacings, ranging from 4 to 12 ft, illustrates clearly the beneficial effects of wide initial spacing and the detrimental effects of carrying too many trees relative to the size to which they will be grown. Not only are trees larger, but yields per acre are greater at wide spacings.

KEYWORDS: Plantation spacing (-growth, stand density, stand development, Douglas-fir, *Pseudotsuga menziesii*.

Reukema, Donald L.
1979. Fifty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-253, 21 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A 51-yr record of observations in stands planted at six spacings, ranging from 4 to 12 ft, illustrates clearly the beneficial effects of wide initial spacing and the detrimental effects of carrying too many trees relative to the size to which they will be grown. Not only are trees larger, but yields per acre are greater at wide spacings.

KEYWORDS: Plantation spacing (-growth, stand density, stand development, Douglas-fir, *Pseudotsuga menziesii*.

Reukema, Donald L.
1979. Fifty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-253, 21 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A 51-yr record of observations in stands planted at six spacings, ranging from 4 to 12 ft, illustrates clearly the beneficial effects of wide initial spacing and the detrimental effects of carrying too many trees relative to the size to which they will be grown. Not only are trees larger, but yields per acre are greater at wide spacings.

KEYWORDS: Plantation spacing (-growth, stand density, stand development, Douglas-fir, *Pseudotsuga menziesii*.

Reukema, Donald L.
1979. Fifty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-253, 21 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A 51-yr record of observations in stands planted at six spacings, ranging from 4 to 12 ft, illustrates clearly the beneficial effects of wide initial spacing and the detrimental effects of carrying too many trees relative to the size to which they will be grown. Not only are trees larger, but yields per acre are greater at wide spacings.

KEYWORDS: Plantation spacing (-growth, stand density, stand development, Douglas-fir, *Pseudotsuga menziesii*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Research Paper PNW-254
April 1979

Evaluation of Sticking Agents Mixed with *Bacillus thuringiensis* for Control of Douglas-Fir Tussock Moth

By John Neisess

CLEMSON UNIVERSITY LIBRARY
JUN 18 1979
SCI. TECH. & AGR. DIV.

cific Northwest Forest and Range Experiment Station
est Service U.S. Department of Agriculture

Metric Conversions

1 centimeter = 0.4 inch
1 milliliter = 0.03 fluid ounce
1 liter = 0.26 gallon
1 gram = 0.035 ounce
1 hectare = 2.5 acres

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

This research was funded by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program. This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation for use by the USDA, nor does it imply registration under FIFRA as amended. Also, mention of a proprietary product does not constitute an endorsement by the USDA.

Evaluation of Sticking Agents Mixed with Bacillus thuringiensis ***for Control of Douglas-fir Tussock Moth***

Reference Abstract

Neisess, John.
1979. Evaluation of sticking agents mixed with *Bacillus thuringiensis* for control of Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-254, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. Spray formulations containing BioFilm, High Tack Fish Glue, and Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *Bacillus thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 cm of rain.

KEYWORDS: Pesticide preparations, *Bacillus thuringiensis* , insecticides (-forest pests, bioassay.

RESEARCH SUMMARY
Research Paper PNW-254
1979

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. The *B. thuringiensis* was mixed in three carrier solutions: water, 25 percent molasses, and 25 percent Sutro, and bioassayed against *Orgyia pseudotsugata* (McDunnough). Of the various stickers tested, only Carboset 525 adversely affected *B. thuringiensis* activity. Spray mixtures containing molasses or Sutro lost more activity after exposure to rain than did the water mixtures, and spray formulations containing BioFilm, High Tack Fish Glue, Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *B. thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 centimeters of rain.

In

mi
app
St
ad
we
of

le

pl
th

st
ad

et

or
s

ntroduction

The microbial insecticide, *Bacillus* *uringiensis*, has most commonly been xed as an aqueous suspension for plication against forest insects. icking agents have sometimes been ded to the spray mixtures to increase atherability by reducing losses activity from washoff by rain. vo 192 and Pinolene were tested by wis and Connola (1966) in *B. thurin- ensis* applications against gypsy th, *Lymantria dispar* (L.). Spore atings of spray residues indicated at the spores remained viable for ice as long as in applications thout sticker. NuFilm, Chevron icker, and BioFilm have also been ded to *B. thuringiensis* spray mixtures ed against forest insects (Yendol al. 1973, Lewis et al. 1974, Stelzer al. 1975), but no evaluations were de of the weathering capabilities the spray mixtures. Laboratory udies by Maksymiuk and Neisess (1975) monstrated that formulations with Film BT increased weatherability about 20 percent.

Many sticking agents are available day that have not been tested for mpatability or weatherability with *B. thuringiensis* spray mixtures. This paper reports on laboratory screening of the weatherability of several new and old sticking agents. Because *B. thuringiensis* has frequently been mixed with 25 percent molasses or Sutro carriers for forest applications, the stickers were evaluated along with carriers to identify combinations that would increase weatherability under laboratory conditions.

Materials and Methods

Eighteen sticking agents were evaluated (table 1). Each was mixed with *B. thuringiensis* in one of three carrier solutions (water, 25 percent molasses, and 25 percent Sutro 970) and then exposed to three levels of rain, 0, 1.27, and 2.54 cm in a completely randomized factorial experimental design. The experiment was conducted with each of three commercial *B. thuringiensis* products, Biotrol 16K, Dipel SC, and Thuricide 32B. The *B. thuringiensis* concentrations were $2.11 \text{ X } 10^6$ international units (IU)/ml (equivalent to $8 \text{ X } 10^9$ IU/gal--a concentration frequently used in forest applications). Liquid sticker concentrations were 1 percent by volume. Polyhall 295

Table 1--Sticking agents and their sources

Sticking agents	Sources
Adsee 775	Witco Chemical Corp.
BioFilm	Colloidal Products Inc.
Carboset 514H	B. F. Goodrich Chemical Co.
Carboset 525	B. F. Goodrich Chemical Co.
Chevron Spray Sticker	Chevron Chemical Co.
Exhalt 800	Kay-Fries Chemical Inc.
Geon 552	B. F. Goodrich Chemical Co.
High Tack Fish Glue	Norland Products Inc.
Hycar 1872X6	B. F. Goodrich Chemical Co.
Nacrylic X4260	National Starch and Chemical Corp.
Nacrylic X4401	National Starch and Chemical Corp.
Nacrylic X4445	National Starch and Chemical Corp.
NuFilm 17	Miller Chemical
Polyhall 295	Stein, Hall and Co., Inc.
Plyac	Allied Chemical Co.
Texcryl 3662	Poly-Acryls, RA Chemical Corp.
Ultra	Sanico
X-Link 2873	National Starch and Chemical Corp.

and Carboset 525, both solids, were mixed at the rate of 0.125 g/100 ml and 1.0 g/100 ml, respectively. The lower rate was used with Polyhall 295 because of thickening properties of this compound.

The same mixing order and procedure was used with all stickers and treatment combinations. The sticker was added to the amount of water needed to make 100 ml of final mix. This mix was agitated until the sticker had either dissolved or become completely suspended. Carboset 525 required an alkaline solution for solubility; 0.5 ml of ammonium hydroxide was added to the water to create a pH range of 7.5-7.7. Molasses or Sutro was then added at the rate of 25 ml/100 ml of total mix and agitated. Finally, the *B. thuringiensis* product was added and agitated again. Treatment combination mixtures that formed water-insoluble precipitates were not evaluated further.

The effectiveness of the sticking agents was evaluated as follows: 0.2 ml of each spray formulation was sprayed onto 10-cm-long cuttings of new growth Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, using an S.T. 4 Laboratory Spray Tower (Burkard Manufacturing Co., Richmans Worth, England). The volume of deposit on the cuttings was determined to be 11.72 (SD = 3.80) µl/g of foliage, which compares to deposits resulting from a 9.35 l/ha application rate in the field (Stelzer et al. 1977). The spray residues were allowed to dry overnight, in total darkness, at room temperature (20-22°C). One prerain sample, at least 2.0 cm long, was cut from each treated cutting and placed in a 50- by 9-mm petri dish with a tight lid. The remainder of the treated cutting was then exposed to simulated rain.

Rain was simulated, with tapwater, using Monarch misting nozzles (6.4-F100C) positioned 1.3 m above the foliage sample. Rain rates were about 2.54 cm/h. After fir cuttings were exposed to 1.27 or 2.54 cm of rain, samples were cut and placed in petri dishes the same as the prerain samples. Five 3-day-old Douglas-fir tussock moth larvae, *Orgyia pseudotsugata* (McD.), from our laboratory colony were placed on the treated samples in the petri dishes. Larvae were also placed on untreated foliage, which was exposed to rain the same as the treated foliage. Five replicates (five larvae/petri dish per replicate) were tested with each treatment at each rain exposure.

Mortality was recorded after the larvae were held at 25.5 ± 1.0°C (78°F) and 40 ± 5 percent relative humidity for 96 h. The percentage of original activity of the *B. thuringiensis* (OAR) remaining after exposure to rain was based upon mortality of larvae that fed on prerain samples. Larval mortality and OAR were used to measure weatherability of the treatments.

Mortality and OAR data were subjecte to analysis of variance. Treatment combinations that formed water-insolubl precipitates upon mixing were treated as missing data. Treatment means were compared using Tukey's w-procedure at the 0.01 level. Data for the three commercial products were analyzed separately.

Results and Discussion

Weatherablity of the various spray formulations varied considerably under the test conditions (tables 2-4). Because many of the sticking agents were acrylic resins or copolymers, they were chemically reactive and formed insoluble precipitates easily (designated by P, tables 2-4). The mixing procedure outlined earlier was designed to dilute the reactive agents as much as possible before combining them. Because even the finest precipitate can plug or reduce the flow in spray system, all mixtures were examine carefully for water-insoluble films.

In a screening experiment of this size, the large number of degrees of freedom in each analysis may result in statistically significant treatment differences that may not be of practica significance, considering that only fiv

Table 2--Weatherability of *Bacillus thuringiensis* (Dipel SC) mixed in 3 aqueous solutions with various sticking agents, measured at 96 hours by percent mortality and percent original activity remaining (OAR) after exposure to simulated rain[1]

Sticking agent	Water					25% molasses					25% Sutro				
	Avg. mortality			Avg. OAR		Avg. mortality			Avg. OAR		Avg. mortality			Avg. OAR	
	Rain (cm)			Rain (cm)		Rain (cm)			Rain (cm)		Rain (cm)			Rain (cm)	
	0	1.27	2.54	1.27	2.54	0	1.27	2.54	1.27	2.54	0	1.27	2.54	1.27	2.54
							Percent								
None	74	53	56	78	80	94	58	56	65	64	96	92	84	97	88
Adsee 775	80	76	76	98	97	96	88	88	93	93	96	76	60	79	62
BioFilm	68	44	60	72	92	100	12	12	12	12	100	64	24	64	24
Carboset 514H	P	P	P	--	--	P	P	P	—	--	P	P	P	—	—
Carboset 525	P	P	P	--	--	P	P	P	--	--	60	60	60	111	115
Chevron Sticker	84	100	80	123	98	100	92	96	92	96	84	84	68	117	95
Exhalt 800	76	92	96	126	132	100	76	76	76	76	100	32	20	32	20
Geon 552	P	P	P	--	--	92	68	56	74	61	96	100	68	105	72
High Tack	92	84	92	97	100	96	88	72	93	76	96	64	48	67	51
Hycar 1872X6	P	P	P	—	--	92	60	60	66	68	P	P	P	—	--
Nacrylic X4260	P	P	P	--	--	92	80	68	89	73	P	P	P	--	--
Nacrylic X4401	96	88	92	93	96	96	92	72	97	76	100	52	68	52	68
Nacrylic X4445	84	84	60	132	92	96	92	52	97	55	P	P	P	--	—
NuFilm 17	84	84	96	102	116	92	88	92	96	101	92	76	68	82	74
Polyhall 295	P	P	P	—	--	96	92	24	97	26	P	P	P	--	--
Plyac	96	100	100	105	105	100	84	92	84	92	88	84	80	95	94
Texcryl 3662	88	84	68	98	82	100	92	96	92	96	96	68	80	71	85
Ultra	84	76	76	94	91	80	48	40	73	67	96	52	76	55	80
X-Link 2873	68	96	80	198	147	96	88	96	91	100	92	44	20	48	22
Average	80.6	74.9	73.8	101.9	97.2	94.9	73.7	65.7	79.1	71.1	92.3	67.7	58.8	76.8	67.9

[1] P = a precipitate formed after mixing.

Table 3--Weatherability of *Bacillus thuringiensis* (Thuricide 32B) mixed in 3 aqueous solutions with various sticking agents, measured at 96 hours by percent mortality and percent original activity remaining (OAR) after exposure to simulated rain[1]

Sticking agent	Water					25% molasses					25% Sutro				
	Avg. mortality			Avg. OAR		Avg. mortality			Avg. OAR		Avg. mortality			Avg. OAR	
	Rain (cm)			Rain (cm)		Rain (cm)			Rain (cm)		Rain (cm)			Rain (cm)	
	0	1.27	2.54	1.27	2.54	0	1.27	2.54	1.27	2.54	0	1.27	2.54	1.27	2.54
							Percent								
None	77	66	45	92	59	96	57	52	61	54	86	60	54	71	57
Adsee 775	88	60	56	66	74	100	76	32	76	32	76	44	20	59	20
BioFilm	88	72	84	83	96	100	84	60	84	60	92	92	80	102	89
Carboset 514H	72	52	44	65	68	96	64	76	69	79	92	47	44	54	47
Carboset 525	100	100	100	100	100	P	P	P	--	--	96	88	64	93	65
Chevron Sticker	80	48	52	61	66	100	64	48	64	48	92	88	72	97	79
Exhalt 800	80	76	52	96	69	96	88	48	91	50	96	76	40	81	42
Geon 552	88	80	48	93	54	96	40	72	40	75	96	72	64	75	67
High Tack	84	80	76	90	102	100	84	80	84	80	92	80	68	90	75
Hycar 1872X6	88	60	55	74	66	92	76	76	84	84	100	56	48	56	48
Nacrylic X4260	92	100	80	109	86	100	100	84	100	84	96	92	72	95	75
Nacrylic X4401	96	88	92	93	95	92	20	16	25	19	96	44	20	44	20
Nacrylic X4445	96	100	96	105	101	92	88	76	96	83	96	96	52	101	53
NuFilm 17	84	59	56	73	73	100	76	48	76	48	96	76	64	79	67
Polyhall 295	100	92	84	92	84	100	96	84	96	84	96	64	52	66	55
Plyac	96	100	76	105	80	100	96	96	96	96	84	72	48	89	51
Texcryl 3662	84	80	76	99	95	P	P	P	--	--	80	44	16	57	18
Ultra	76	92	48	123	63	92	64	44	72	49	100	64	64	64	64
X-Link 2873	88	96	96	114	114	100	80	60	80	60	100	52	49	52	49
Average	85.0	76.3	64.1	91.4	76.7	97.0	72.0	60.8	74.5	62.7	92.4	68.4	52.3	74.9	54.9

[1] P = a precipitate formed after mixing.

Literature Cited

Angus, T. A., and P. Luthy.
1971. Formulations of microbial insecticides. *In* Microbial control of insects and mites, p. 623-638. H. D. Burges and N. W. Hussey, eds. Academic Press, New York.

Lewis, Franklin B., and Donald P. Connola.
1966. Field and laboratory investigations of *Bacillus thuringiensis* as a control agent for gypsy moth, *Porthetria dispar* (L.). USDA For. Serv. Res. Pap. NE-50, 39 p. Northeast. For. and Range Exp. Stn., Upper Darby, Pa.

Lewis, F. B., N. R. Dubois, D. Grimble, W. Metterhouse, and J. Quimby.
1974. Gypsy moth: Efficacy of aerially-applied *Bacillus thuringiensis*. J. Econ. Entomol. 67(3): 351-354.

Maksymiuk, Bohdan, and John Neisess.
1975. Physical properties of *Bacillus thuringiensis* spray formulations. J. Econ. Entomol. 68(3):407-410.

Stelzer, Milton J., John Neisess, and C. G. Thompson.
1975. Aerial applications of a nucleopolyhedrosis virus and *Bacillus thuringiensis* against the Douglas-fir tussock moth. J. Econ. Entomol. 68(2):269-272.

Stelzer, Milton J., J. Neisess, J. C. Cunningham, and J. R. McPhee.
1977. Field evaluation of baculovirus stocks against Douglas-fir tussock moth in British Columbia, J. Econ. Entomol. 70(2):243-246.

Yendol, William G., Ronald A. Hamlen, and Franklin B. Lewis.
1973. Evaluation of *Bacillus thuringiensis* for gypsy moth suppression. J. Econ. Entomol. 66:183-186.

* * * * * * *

GPO 988-122

Neisess, John.
1979. Evaluation of sticking agents mixed with *Bacillus thuringiensis* for control of Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-254, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. Spray formulations containing BioFilm, High Tack Fish Glue, and Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *Bacillus thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 cm of rain.

KEYWORDS: Pesticide preparations, *Bacillus thuringiensis*, virus (-forest pest control, bioassay.

Neisess, John.
1979. Evaluation of sticking agents mixed with *Bacillus thuringiensis* for control of Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-254, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. Spray formulations containing BioFilm, High Tack Fish Glue, and Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *Bacillus thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 cm of rain.

KEYWORDS: Pesticide preparations, *Bacillus thuringiensis*, virus (-forest pest control, bioassay.

Neisess, John.
1979. Evaluation of sticking agents mixed with *Bacillus thuringiensis* for control of Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-254, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. Spray formulations containing BioFilm, High Tack Fish Glue, and Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *Bacillus thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 cm of rain.

KEYWORDS: Pesticide preparations, *Bacillus thuringiensis*, virus (-forest pest control, bioassay.

Neisess, John.
1979. Evaluation of sticking agents mixed with *Bacillus thuringiensis* for control of Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-254, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Eighteen sticking agents were evaluated for their ability to prevent loss of insecticidal activity of *Bacillus thuringiensis* formulations after exposure to simulated rain. Spray formulations containing BioFilm, High Tack Fish Glue, and Nacrylic X4260 and X4445, NuFilm 17, Plyac, and X-Link 2873 were the most active after exposure to rain. About 30 percent of the activity of *Bacillus thuringiensis* spray mixtures without stickers was lost after exposure to 2.54 cm of rain.

KEYWORDS: Pesticide preparations, *Bacillus thuringiensis*, virus (-forest pest control, bioassay.

Lit

Angu
19

Lewi
Conn
19

Lewis
W. Me
197
a
g
3

Maksy
197
t
J

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: *Pacific Northwest Forest and Range*
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Research Paper PNW-255
May 1979

CLEMSON UNIVERSITY LIBRARY
AUG 7 1979
SCI., TECH. & AGR. DIV.

Long-term Growth of EIGHT LEGUMES Introduced at Three Forest Locations in Southwest Oregon

RICHARD E. MILLER / RAY ZALUNARDO

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

AUTHORS

RICHARD E. MILLER is Principal Soil Scientist, Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Olympia, Washington. RAY ZALUNARDO is Wildlife Biologist, Umqua National Forest, Roseburg, Oregon.

ENGLISH EQUIVALENTS

1 meter = 3.281 feet
1 hectare = 2.471 acres
1 millimeter = 0.3937 inch
1 kilogram = 2.205 pounds
1° C = 1.8° F

Long-Term Growth of Eight Legumes Introduced at Three Forest Locations in Southwest Oregon

Reference Abstract

Miller, Richard E., and Ray Zalunardo.
1979. Long-term growth of eight legumes introduced at three forest locations in southwest Oregon. USDA For. Serv. Res. Pap. PNW-255, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Using nitrogen-fixing plants in forestry becomes financially more attractive as the costs of fertilizers and their application continue to increase. Eight legume cultivars were screened for suitability in Douglas-fir forests of southwest Oregon. The legumes were sown on concurrently fertilized and unfertilized plots within deer exclosures in three logged and burned clearcuts. Percent cover after the first and during the ninth growing season was clearly greater on 2- by 2-meter plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover but not subsequent plant cover or height. N fixation was not measured; however, all surviving species were nodulated.

KEYWORDS: Nitrogen fixation, leguminous plants, soil moisture, soil temperature, seeding (erosion control), fertilizer response (soil).

RESEARCH SUMMARY
Research Paper PNW-255
1979

Legumes can improve the status of nitrogen and organic matter in soils and thereby can increase growth of associated vegetation. To test the suitability of eight agricultural legumes for forestry uses in the western Cascades of southwest Oregon, we conducted a field trial on three recently burned clearcuts. The legumes were broadcast seeded on concurrently fertilized and unfertilized plots within deer exclosures.

Percent legume cover after the first and during the ninth growing seasons was clearly greater on 2-m x 2-m plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover, but not subsequent plant cover or height. N-fixation was not measured; however, all surviving species were nodulated. The Douglas-fir near or on the legume plots did not survive the second growing season. Thus, we have no measure of the benefits from these legumes to either the associated vegetation or the soil.

Some of these species could be used in forest management to stabilize soil disturbed by road construction or logging, or to improve growth of associated trees. Characteristics of some species are desirable for both applica-

tions; others are not. For example, ease of initial plant establishment over a wide range of site conditions is a desirable characteristic for stabilizing soil and improving growth of associated trees. Alfalfa, birdsfoot deervetch (trefoil) and particularly crownvetch provided well-stocked stands at all locations when sown with 22.4 kg of seed per hectare. Three of the legumes frequently dominated associated vegetation. This trait is more desirable for soil protection than for silvicultural uses, especially if legumes are admixed with seedlings during plantation establishment. Sowing crownvetc or climbing legumes like flatpea or hairy vetch under pole-size trees, however, may be desirable to insure competitiveness with natural vegetation.

The widespread success of N fertilizers for increasing conifer growth in western Washingto and Oregon justifies additional research and development of N-fixing plants as alternative means for supplying N. Some of the legumes tested in this trial on harsh sites may fit this purpose.

CONTENTS

Page

INTRODUCTION 1

STUDY AREAS 1

METHODS 2
  General 2
  Plant Materials 2
  Fertilization 3
  Conifer Seeding and Planting 3
  Plant Observations 3
  Environmental Measurements 4
  Statistical Analysis 4

RESULTS AND DISCUSSION 4
  First- and Second-Year Emergence and Cover . . . 4
  Nine-Year Survival, Growth, and Spread 6
  Species Summaries 7
  Effects of Fertilization 10
  Suitability in Forest Management 10

CONCLUSIONS 10

LITERATURE CITED 11

INTRODUCTION

Legumes can improve the status of nitrogen and organic matter in soils and can thereby increase growth of associated vegetation. Using N-fixing plants in agriculture and forestry becomes financially more attractive as the costs of nitrogen fertilizers and their application continue to increase. We conducted a field trial to test the suitability of some agricultural legumes for use in forests of the western Cascade Range of Oregon. We report the 9-year survival and growth of eight legume cultivars sown in three logged and burned clearcuts. We contrast their performance on fertilized and unfertilized plots. We also intended to measure the effects of these legumes on an associated conifer, but seedlings from Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) seeds sown concurrently with the legume seeds failed to survive. Our results show that several of these legumes established vigorous stands in these severe growing conditions.

STUDY AREAS

Location.--Our species trial was located within 0.4-hectare, fenced deer exclosures in three recently clearcut areas in the western Cascade Range east of Roseburg, Oregon (fig. 1). These areas were considered representative of the 600- to 900-m (2,000- to 3,000-ft) elevational zone of the Umpqua River drainage; north, south, and southeast aspects were presented (table 1).

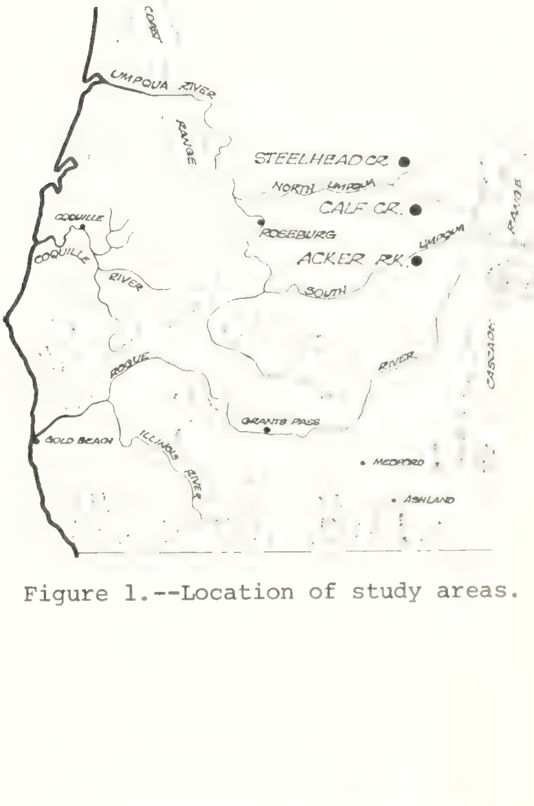


Figure 1.--Location of study areas.

Table 1--Description of the study areas in southwest Oregon

Characteristic	Study areas		
	Calf Creek	Steelhead Creek	Acker Rock
Elevation (meters)	900	760	670
Slope (percent)	[illegible]	10	[illegible]
Aspect	N.	SE.	S.
Soil texture:			
0-10 cm	loam	clay loam	loam
40-50 cm	clay loam	clay	clay loam
Bulk density[1] (g/cm^3):			
0-10 cm	[illegible]	0.79	[illegible]
40-50 cm	1.19	1.29	1.34
Tentative soil series	Acker	Freezener	Acker

[1] Of soil < 2 mm in diameter.

Vegetation.--The preceding old-growth, mixed-conifer forests were predominantly Douglas-fir, with some sugar pine (*Pinus lambertiana* Dougl.) and incense-cedar (*Libocedrus decurrens* Torr.). Logging slash from these stands was broadcast burned 5 to 17 months before the legumes were sown in spring 1965. The sparse vegetation that developed after burning was pulled from the plots before the legumes were sown (fig. 2).

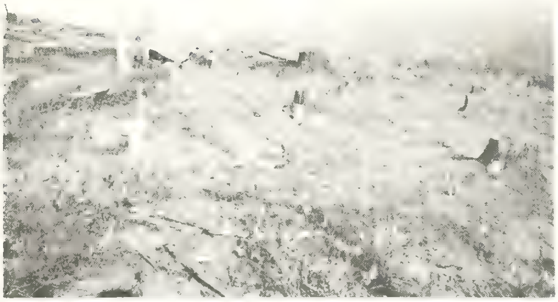


Figure 2.--Initial site conditions before sowing at the Steelhead Creek location.

Soils.--Soils of the study areas were deep or moderately deep, well-drained loams or clay loams developed on tuffs and breccias of the extensive Little Butte Volcanic Series (Peck et al. 1964). Clay content and bulk density in these soils gradually increased with soil depth (table 1). The most obvious differences among the soils were in color and structure of the surface soils. At Steelhead Creek, the surface soil consisted largely of hard soil aggregates or "shot;" these were less prevalent at the other locations. Moreover, the dark red-brown soil at Steelhead Creek contrasted sharply with the yellow-brown soils at Calf Creek and Acker Rock. These soil colors were consistent with those of the original pyroclastic parent material.

Climate.--The Mediterranean-type climate of the study areas is characterized by extended periods of drought during the summer. Past annual precipitatio averaged 1 524 mm (60 in) at Calf Creek and Steelhead Creek and 1 016 mm at Acker Rock, the most southerly location (Pacific Northwest River Basins Commission Meteorological Committee 1969). Average evaporation stress (Class A Pan) was 1 068 mm and similar for all locations.

METHODS

General

Emergence, survival, spread, and nodulation of each legume were observed on three plots at each location. Two of the three plots were fertilized. Air and soil temperatures, precipitation, and soil moisture content were samples periodically during the first two growing seasons after sowing.

Plant Materials

Seeds of annual or perennial legumes were sown on 2- by 2-m (1 milacre) plots at amounts equal to 22.4 kg/ha for each species. Based on a generally recommended seed density for broadcast sowing of 1,550 live, germinable seeds per square meter (Berglund 1976), our sowing provided excessive seed density for the small-seeded deervetches and sparse density for the remaining, heavier-seeded species (table 2). Each species was randomly assigned to a block of three plots at a given location; the plots were separated by 1.2-m-wide buffer strips. Sowing occurred between March 24 and April 6, 1965; however, the Washington lupine was sown about 1 month later. Although seeds of most species were broadcast without covering to simulate helicopter application, those

Table 2--Plants[1] sown at the three study areas

Common name	Scientific name	Variety	Seeds per kg	Live no. of pure seeds per m^2 [3]
			Thousands	
Alfalfa	*Medicago sativa* L.	DuPuits	496	(939)
Crownvetch	*Coronilla varia* L.	Penngift	297	519
Birdsfoot deervetch (trefoil)	*Lotus corniculatus* L.		1,058	(1,927)
Wetland deervetch (Big trefoil)	*Lotus uliginosus* Schkuhr.	Beaver	2,250	(4,126)
Washington lupine	*Lupinus polyphyllus* L.		40	(72)
Bitter-blue lupine	*Lupinus angustifolius* L.	Spooner	6	13
Flatpea	*Lathyrus sylvestris* L.		22	(44)
Hairyvetch	*Vicia villosa* Roth.		38	(77)

[1] Scientific and common names are according to Harlan P Kelsey and William A. Dayton, Standardized plant names. 675 p. J. Horace McFarland Co., Harrisburg, Pa., 1942; other common names are shown in parentheses

[2] Seeds donated by Northrup, King, and Company, Albany, Oregon; Grasslyn Company, College Park, Maryland, J. J. Astor Experiment Station, Astoria, Oregon; and Spooner Branch Experiment Station, Spooner, Wisconsin.

[3] Based on sowing 22.4 kg/ha and known or assumed seed purity and germination percentages. Assumed figures are shown in parentheses.

Table 3--Fertilizer treatments applied to each species at the three study areas

Treatment	Fertilizer		Element			
	Type	Rate of application	N	P	K	S
	- - - - - - - - - - - - -	kg/ha	- - - - - - - - - - -			
None						
NPKS	15-10-10[1] with microelements	1,120	168	49	92	168
PS	0-45-0	250	0	49	0	25

[1] This specially formulated fertilizer was donated by the Pacific Supply Cooperative, Portland, Oregon.

of both lupines were spot-seeded and covered with 2 cm of soil.

All seeds were inoculated with either an appropriate commercial inoculum or with soil from an established stand of the same species; the seeds were also treated with a commercial molybdenum solution, "Moly-grow," [1] to promote N fixation.

Fertilization

Fertilizer treatments were systematically assigned to the three plots of each species at each location. The first plot remained unfertilized, the second was fertilized with a complete fertilizer (NPKS), and the third was fertilized with treble superphosphate (PS) to provide an amount of phosphorous equivalent to that in the complete fertilizer. Both fertilizers contained sulfur (table 3).

Conifer Seeding and Planting

Stratified Douglas-fir seeds were also sown concurrently with the legumes. Nine seedspots, each with three to four seeds, were established within each plot; buffer areas were seeded at the same time and spacing. Because seed germination was extremely poor at Steelhead Creek, two 2+0 Douglas-fir seedlings were planted there in each plot in late spring (1965).

Plant Observations

Legume growth was observed, photographed, and measured at periodic intervals after sowing. The percentage of plot area covered by legumes was ocularly estimated by two observers to the nearest 20 percent in December after the first and second growing seasons. This crude estimate of cover reduced the sensitivity of subsequent statistical analyses; therefore, for the final evaluation made in the middle of the ninth growing season, cover was ocularly estimated to the nearest 5 percent. Then, height of representative plants and maximum distance each species had spread from its plot boundaries was also measured and presence of root nodules was checked on each plot by digging up one of any surviving plants.

---

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Environmental Measurements

Temperature and precipitation at each area were measured at biweekly intervals during the first two growing seasons. Maximum and minimum temperatures were measured with standard mercury and alcohol thermometers at 1-m height; the thermometers were shielded from direct sunlight. Maximum soil surface temperature at two locations per area was recorded by half-buried "Tempils" that melted at specific temperatures over a range of temperatures.

Composite soil samples were collected periodically near the legume plots during the first growing season. Volumetric samples were removed at 10-cm intervals to a depth of 50 cm or more. Two to eight 100-cm^3 samples from each depth class were composited in plastic-lined bags and sealed to prevent moisture loss; moisture content and bulk density were later measured gravimetrically in a subsample dried at 105°C. Soil moisture retention at 3, 8, and 15 bars was determined with a pressure-plate apparatus and at 25 bars by a pressure-membrane apparatus (U.S. Salinity Lab Staff 1954). Gravel, between 2.00- and 6.35-mm diameter, was left in the moisture and moisture-retention samples, because these weathered stone and hard aggregates contained substantial amounts of moisture. Percentages of (1) coarse gravel over 6.35-mm diameter and (2) fine gravel, 2.00- to 6.35-mm diameter were determined by weighing after drying. Particle-size analyses of sand, silt, and clay (2-h settling time) were made by the hydrometer method (Day 1956).

Statistical Analysis

Data were analyzed as a randomized block, split-plot design with species as the whole-plot treatment and fertilizer as the split-plot treatment. Analysis of variance (MANOVA) and orthogonal comparisons were used to identify significant factors and significant differences among means. A probability level of $P<0.05$ was used to judge statistical significance.

RESULTS AND DISCUSSION

First- and Second-Year Emergence and Cover

By the end of the first growing season, the legume species varied greatly in percent cover (table 4). All species had emerged and had established cove at Calf Creek; only two species performed as well at Steelhead Creek or at Acker Rock (table 4)

Table 4--Average foliar cover after the first growing season, by species and study area[1]

Species	Location		
	Calf Creek	Steelhead Creek	Acker Rock
		Percent	
Alfalfa	60	60	33
Crownvetch	80	27	7
Birdsfoot deervetch	87	73	33
Location average	76	53	24
Wetland deervetch	67	7	0
Washington lupine	13	0	13
Bitter-blue lupine	53	20	0
Flatpea	40	0	0
Hairy vetch	60	13	0
Location average, all species	58	25	11

[1] Averages the percent cover on two fertilized and one unfertilized plot per species at each location.

The absence of measurable cover for some species in the 1st and especially in subsequent years restricted statistical analysis of performance to that of three species, alfalfa, crownvetch, an birdsfoot deervetch (trefoil); these clearly outperformed the other species (table 4). Averag over all areas and fertilizer treatments, 1st-year cover did not differ significantly among the three species ($P<0.22$) (table 5); however, birdsfoot deervetch had the greatest averag cover (64 percent).

Table 5--Average foliar cover after the first growing season, by species and fertilizer treatment

Species	Fertilizer			Species average
	None	NPKS	PS	
	Percent			
lfalfa	53	80	20	51
rownvetch	33	40	40	38
irdsfoot	73	67	53	64
Fertilizer average	53	62	38	51

Although 1st-year plant cover f these three species varied idely among the three areas, he non-random selection of the reas precluded tests of statisical significance. Average over was 76 percent at Calf reek, 53 percent at Steelhead reek, and 24 percent at Acker ock (table 4). Average cover n fertilized plots did not ignificantly differ from that n unfertilized plots; however, he two fertilizers had differing ffects ($P<0.05$). Plots treated ith NPKS averaged greater cover 62 percent) than those fertilized ith PS (38 percent) (table 5). his general trend of more cover ollowing a complete fertilizer id not vary significantly among he three species.

Foliage cover generally inreased by the end of the second rowing season. Some of this ncrease was from new germination uring the 2d year. Some of these ew germinants probably came from ard seeds which are usually mpermeable to water; for example, he crownvetch seedlot had 20 ercent of hard seed. Cover on he PS-treated plots had improved reatly and was no longer signifiantly less than that on plots ertilized with NPKS.

Differences in growing condiions probably explained the ariable performance of species mong the locations. High temerature and moisture stress enerally characterized the rowing conditions for seed and lants during the first growing season. Although maximum air temperature was similar at the three locations, maximum temperature at the soil surface varied greatly. The microclimate at Calf Creek with its north aspect was probably the most favorable (table 6). Average 1st-year cover was also greatest at this location (table 4). Although the darker colored soil at Steelhead Creek was consistently hottest and presumably more hostile for seed germination and seedling survival, 1st-year cover was better there than at Acker Rock. The greater air temperature on the south aspect at Acker Rock (table 6) suggests that greater evaporational stress may have reduced plant performance at this location.

Table 6--Maximum monthly air and soil surface temperature during the first growing season at the three study areas

Month	Air temperature			Soil surface temperature		
	Calf Creek	Steelhead Creek	Acker Rock	Calf Creek	Steelhead Creek	Acker Rock
	°C					
May	29	29	31	[illegible]	[illegible]	52
June	32	31	34	52	[illegible]	66
July	35	36	38	[illegible]	73	[illegible]
August	38	[illegible]	[illegible]	59	[illegible]	[illegible]
September	34	[illegible]	[illegible]	52	73	59
Average	34	34	36	[illegible]	68	62

Moisture stress accompanied these high temperatures. The seeding in March was on soil that was thoroughly moist from previous winter storms. When the perennial lupine seeds were sown in early May, however, soil moisture tension in the 0- to 10-cm layer at Steelhead Creek was already at 10.2 bars (table 7). During May through September in the first growing season, only 64 to 76 mm of rain were measured at the three study areas. All locations showed a general increase in soil moisture tension during the growing season; temporary reductions in tension followed sporadic rainfall.

Table 7--Soil moisture tension during the first growing season, by study area and sampling month[1]

Date	Location		
	Calf Creek	Steelhead Creek	Acker Rock
	Bars		
April 6	0.2	9.5	0.8
May 13	.6	10.2	2.9
June 2	1.5	16.9	3.4
June 16	1.1	5.2	6.8
July 2	9.6	[2](29.0)	13.5
July 20	(51.9)	(74.2)	—
September 2	10.1	(93.3)	(36.5)

[1] Soil moisture tensions were determined for the 0- to 10-cm layer.

[2] Values in parentheses are extrapolated.

Rates of germination and seedling growth generally decrease as the soil dries and hold the remaining moisture with greater force. Germination of garden pea and vetch seeds, however, was not affected by soil water until retention reached 3.8 bars, provided the soil conducted a continuing supply of water to the seed and the seed contacted a sufficient area of the soil (Hadas and Russo 1974a). To ensure an adequate seed-soil contact area, seed diameter should be at least five times the diameter of adjoining soil aggregates (Hadas and Russo 1974b). Large soil aggregates, such as those at Steelhead Creek, retard evaporation from the soil by reducing rate of moisture conductivity, but they slow the rate at which moisture moves to the seed and reduce the seed-soil contact area.

Although germination was probably most disadvantaged at Steelhead Creek, where soil aggregates were especially large, we have no measure of rate and amount of seed germination. Our percentage of plant cover after the first growing season reflects not only germination, but also emergence, survival, and growth. We can reasonably conclude, however, that the three areas represented a wide range of environmental conditions and that the better initial performance of all species at Calf Creek was related to more favorable conditions for germination and growth at that area.

Nine-Year Survival, Growth, and Spread

By the middle of the ninth growing season, seven of the eight species were still present at Calf Creek and only four at Steelhead Creek and Acker Rock (table 8). Foliage cover averag 79 percent at Calf Creek compare to 42 and 35 percent at Steelhea Creek and Acker Rock. Statistic analysis was again limited to co paring alfalfa, crownvetch, and birdsfoot, the three species wit sufficient survival data. In the ninth growing season, difference among these three species were statistically significant (P<0.05

Table 8--Average foliar cover during the ninth growing season, by species and study area

Species	Location		
	Calf Creek	Steelhead Creek	Acker Rock
	Percent		
Alfalfa	97	12	5
Crownvetch	100	97	83
Birdsfoot deervetch	40	18	17
Location average	79	42	35
Wetland deervetch	27	0	0
Washington lupine	7	0	2
Bitter-blue lupine	0	0	0
Flatpea	7	0	0
Hairy vetch	30	23	0
Location average, all species	39	19	13

Average foliage cover on the crownvetch plots had increased from 38 percent after year 1 to 93 percent in year 9; in contrast alfalfa and birdsfoot declined from 51 and 64 percent after year 1 to 38 and 25 percent, respectively, in year 9 (table 9)

Table 9--Average foliar cover at the three study areas during the ninth growing season, by species and fertilizer treatment

Species	Fertilizer			Species average
	None	NPKS	PS	
		Percent		
Alfalfa	45	35	33	38
Crownvetch	97	90	93	93
Birdsfoot	30	23	22	25
Fertilizer average	57	49	49	52

rcent cover was no longer lated to fertilizer treatment; e initial benefit from the mplete fertilizer over the eble superphosphate was not atistically significant in e 2d and 9th years.

Average height of the 9-year- d legume stands was similar at lf Creek (39 cm) and Steelhead eek (42 cm) and nearly twice at at Acker Rock 22 cm). erage height also varied widely ong the three species and rtilizer treatments (table 10), t none of these differences s statistically significant.

Table 10--Average height and maximum distance of spread at three study areas during the ninth growing season, by species and fertilizer treatment

Species	Fertilizer			Average
	None	NPKS	PS	
	Average height (cm)			
alfa	52	48	17	39
wnvetch	52	37	37	42
dsfoot	26	25	35	28
ertilizer average	43	37	29	36
	Maximum distance spread from plot (cm)			
alfa	0	0	0	0
wnvetch	260	175	188	208
dsfoot	23	88	85	66
ertilizer average	94	88	91	91

The distance that specific gumes spread from the location sowing may influence choice species. Where extensive reading is desired, crownvetch a clear choice among the ree species that showed constent survival (table 10). though distance of spread was milar at the three locations, was influenced by fertilizer eatment. Crownvetch and rdsfoot reacted significantly fferently to fertilization; ereas crownvetch spread farther om unfertilized plots, birdsoot did not.

Although all surviving species were nodulated, we did not record nodule numbers, size, or color. The Douglas-fir sown or planted near or on the legume plots did not survive the second growing season. Thus, we have no measure of the benefits from these legumes to either the associated vegetation or the soil.

Species Summaries

Additional discussion about individual species follows:

Alfalfa.--This perennial species grew well at all trial locations (fig. 3). It possessed a large, deeply penetrating tap root. Initial vigor of the stands was improved by the complete fertilizer and reduced by treble superphosphate. Especially at Acker Rock, alfalfa growth started much earlier and continued longer in the second growing season on plots treated with the complete fertilizer. Except for limited clipping by rabbits, the foliage was not utilized; therefore, the lack of a continued fertilizer effect through nutrient recycling is puzzling.

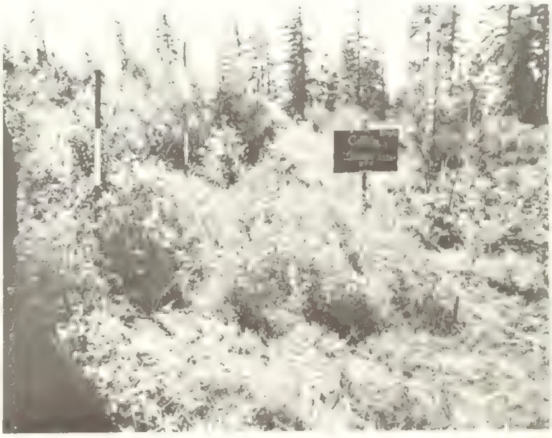


Figure 3.--Nine-year-old stand of alfalfa at Calf Creek.

Crownvetch.--Cover of this perennial species increased steadily after the first growing season and averaged 93 percent during the ninth growing season. Moreover, this was the only species to spread from all original plots. Although crownvetch was initially slow to cover the plots at Steelhead Creek and Acker Rock, it attained nearly complete coverage by the 9th year (fig. 4). Fertilizer apparently provided little increase in final stocking or stand height; however, the chlorotic unfertilized stand at Acker Rock contrasted sharply with the dark green of both fertilized plots.

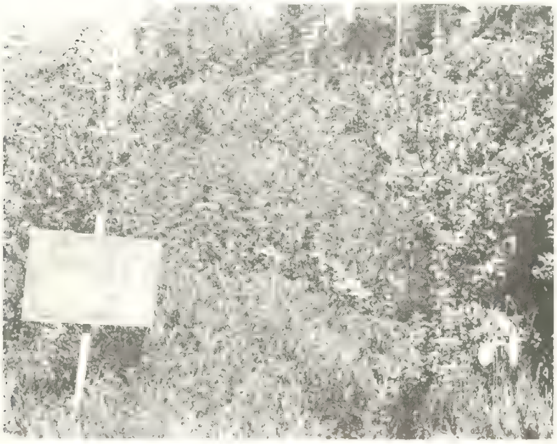


Figure 4.--Nine-year-old stand of crownvetch at Steelhead Creek.

The three varieties of crownvetch adapt to a wide range of site conditions (McKee 1964, McKee and Langille 1967). Crownvetch is frequently used to revegetate cut and fill slopes along highways and mine spoils in the East and Midwest. Although crownvetch can penetrate imperfectly drained, heavy clay soils, it generally is less effective than birdsfoot deervetch (trefoil) on imperfectly or poorly drained soil (Hawk 1964, Waddington 1968). Crownvetch grows well in medium shade of Eastern conifers and deciduous trees; however, it grows best in full sunlight and poorly in full shade.[2] Root growth is affected more by shade conditions than is top growth (Langille and McKee 1970).

Local experience with crownve is limited and generally unsuccessful. Dyrness (1967) sowed inoculated seed of the "Emerald" variety in both fall and spring on a compacted landing at 520-m elevation in the western Cascade Range. Although seed germinatio was good to excellent, mortality was high during the next growing season and winter; final surviva and vigor were poor. The Soil Conservation Service has had little success with crownvetch in the Northwest.[3] Although crownvetch is not listed as a suggested species to control erosion along forest roads in Oregon (Berglund 1976), our observations justify new interes

Birdsfoot deervetch (trefoil,-- The average cover of birdsfoot declined from 65 percent after the first growing season to 25 percent by the ninth growing season; this perennial species spread about 1 m beyond the original plots. Fertilization had no consistent effect on either foliage cover or plant height.

Dyrness (1967) reported good to excellent germination and initial establishment at his test location in the Coast Range and at one in the western Cascad Range; however, final stocking was seriously reduced by frost heaving. In contrast, Klock et al. (1975) observed no emergence of fall-sown birdsfoot at four locations in the cooler, drier mountain slopes in north central Washington (900- to 2 100-m elevations). Birdsfoot is generally considered a long-lived, winter hardy species adapted to subalpine conditions and annual precipitation between 460 and 1 500 mm (Berglund 1976). Our field trial supports this general observation.

---

[2] Written correspondence with Fred V. Grau, President, Grasslyn Company, College Park, Maryland, on January 5, 1965.

[3] Personal correspondence with Jack R. Carlson, Plant Material Specia ist, Soil Conservation Service, Spokan Washington, on June 5, 1978.

Wetland deervetch (big trefoil).--This perennial deervetch or trefoil performed poorer than birdsfoot in our trial. Survivors were present only at the more mesic Calf Creek location, where cover averaged about 30 percent. Fertilization had no apparent effect.

Dyrness (1967) reported good initial survival and growth but much winter mortality at his location in the Oregon Cascade Range. The better performance reported for his Coast Ranges site and our findings are consistent with general recommendations to use this species where effective precipitation exceeds 1 524 mm (Berglund 1976).

Washington lupine.--Initial and final establishment of this perennial lupine was limited to Calf Creek and Acker Rock; no seedlings emerged at Steelhead Creek, probably because our late sowing was in a dry soil. The 9-year-old plants were robuts (Fig. 5). Although some new plants developed from seed, they were few in number presumably because of seed depredation by birds or rodents. An auxiliary sowing on a highly compacted skid road at Acker Rock produced vigorous and persistent plants. This species has been used in Germany and elsewhere in Europe to improve nitrogen and organic conditions of raw humus soils (Miller 1964).

Bitter-blue lupine.--No live plants of this annual were present after the first growing season. The original seedlings produced second generation plants at Calf Creek and Steelhead Creek, but not at Acker Rock. Seed produced by these plants was probably consumed by birds; thus, the complete dependence of this annual on seed propagation lowered its chances to produce a long-lived stand.

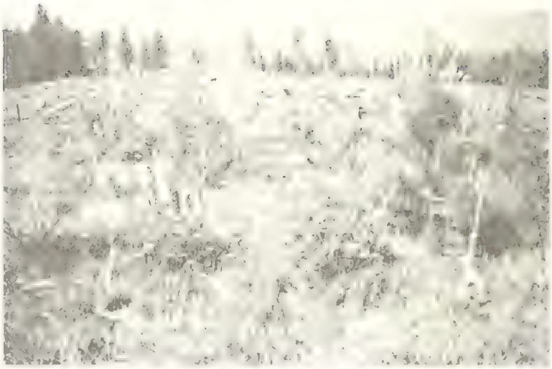


Figure 5.--Nine-year-old Washington lupine and ponderosa pine at Calf Creek.

Flatpea.--Initial and final establishment of this long-lived perennial was limited to Calf Creek; the few surviving plants appeared healthy but were confined to a single plot. Dyrness (1967) also reported poor germination at both his Cascade and Coast Ranges locations; however, his transplanted seedlings did well. Grunder and Dickson (1948) summarized the use and cultural practices necessary for flatpea in the Pacific Northwest. They stressed its slow early development but ability to compete with native vegetation.

Hairy vetch.--This annual established itself initially at Calf Creek and Steelhead Creek and persisted there. Hairy vetch bested other species at both locations by spreading up to 8 m from the original plots; vigorous plants climbed and dominated associated vegetation. The effects of fertilization were indefinite.

Effects of Fertilization

In some species at some locations, the complete NPKS fertilizer applied at seeding time apparently increased initial cover and plant vigor. Fertilization with nitrogen and phosphorous is generally assumed necessary for successful grass establishment along forest roads of Oregon (Berglund 1976). Unexplainably, however, the effect of superphosphate was to reduce 1st-year foliage cover, especially of alfalfa.

Suitability in Forest Management

Some of these species could be used in forest management to stabilize soils disturbed by road construction or logging or to improve growth of associated trees. Characteristics of some species are desirable for both applications; others are not. For example, ease of initial plant establishment over a wide range of site conditions is desirable for stabilizing soil and improving growth of associated trees. Alfalfa, birdsfoot deervetch, and particularly crownvetch provided well-stocked stands at all locations when sown with 22.4 kg of seed per hectare. This was equivalent to about 939, 1,927, and 519 live pure seeds per square meter respectively, compared to 1,550 per square meter recommended for adequate erosion control along forest roads (Berglund 1976).

Long-lived perennials are generally preferable to annuals whose performance depends on regular production, survival, and germination of seeds. Six of the eight legumes tested were perennial; the exceptions were the two annuals, bitter-blue lupine and hairy vetch. Of the three top performers, crownvetch was particularly well adapted. This perennial legume normally seeds profusely and also spreads with new shoots from widely ramifying lateral roots.[4] Stems range from 0.6- to 1.8-m long and are strongly branched. Its deeply penetrating root system has numerous lateral roots (McKee 196

Three of the legumes frequentl dominated associated vegetation. This trait is more desirable for soil protection than for silvicultural uses, especially if legumes are admixed with seedling during plantation establishment. Sowing crownvetch or climbing legumes like flatpea or hairy vetch under pole-sized trees, however, may be desirable to ensure competitiveness with natural vegetation.

Finally, shade tolerance is another trait that influences species choice. If continued nitrogen fixation is desired, then the ability to grow well in the partial shade of other plants is essential. Crownvetch (McKee 1964, Hawk 1964), flatpea[5] and Washington lupine have this desired trait.

CONCLUSIONS

1. Alfalfa, birdsfoot deervet (trefoil), and especially crownvetch formed well-stocked stands during a 9-year period after sowi on recently burned clearcuts in the western Cascade Range of sout west Oregon; survival and foliage cover by five other legumes sown at the same rate of 22.4 kg of seed per hectare was much poorer, especially on harsher sites.

---

[4] Personal correspondence with Guy W. McKee, Agronomist, The Pennsylvania State University, University Park, Pennsylvania, on May 22, 1978.

[5] Personal communication with Jack R. Carlson, Plant Materials Specialist, Soil Conservation Service, Spokane, Washington, on November 4, 1977.

2. All surviving species leveloped nodules on their roots. lthough we didn't know if these odules were functional, their resence and the vigorous top rowth suggest that these legumes ould improve forest growth by dding N-rich organic matter to he soil.

3. Fertilization with a com- lete fertilizer or with super- hosphate did not affect legume urvival or growth after the st year.

4. The widespread success of fertilizers in increasing onifer growth in western Washing- on and Oregon justifies addi- ional research and development f N-fixing plants as alternative eans for supplying nitrogen. ome of the legumes tested in his field trial at three harsh ites may fit this purpose.

ITERATURE CITED

erglund, Erwin R.
1976. Seeding to control erosion along forest roads. Oreg. State Univ. Ext. Serv. Ext. Circ. 885, 19 p. Corvallis.

ay, Paul R.
1956. Report of the Committee on Physical Analyses, 1954-1955, Soil Science Society of America. Soil Sci. Soc. Am. Proc. 20:167-169.

yrness, C. T.
1967. Grass-legume mixtures for roadside soil stabilization. USDA For. Serv. Res. Note PNW-71, 19 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

runder, Maynard S., and Newell . Dickson.
1948. Flat pea. Agric. Exp. Stn. Mimeogr. Circ. 104, 8 p. West. Wash. Exp. Stn., Puyallup.

adas, A., and D. Russo.
1974a. Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil water contact. I. Experimental study. Agron. J. 66:643-647.

Hadas, A., and D. Russo.
1974b. Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil water contact. II. Analysis of experimental data. Agron. J. 66:647-652.

Hawk, Virgil B.
1964. Soil requirements and establishment of crownvetch. Proc. Crownvetch Symp. 1964: 6-8. Penn. State Univ., University Park.

Klock, Glen O., Arthur R. Tiedemann, and William Lopushinsky.
1975. Seeding recommendations for disturbed mountain slopes in north central Washington. USDA For. Serv. Res. Note PNW-244, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Langille, Alan R., and Guy W. McKee.
1970. Early growth of crownvetch under reduced light. Agron. J. 62:552-554.

McKee, Guy W.
1964. Cultivated varieties - origin and description. Proc. Crownvetch Symp. 1964:3-8. Penn. State Univ., University Park.

McKee, Guy W., and Alan R. Langille.
1967. Effect of soil pH, drainage, and fertility on growth, survival and element content of crownvetch, *Coronilla varia* L. Agron. J. 59:533-536.

Miller, Richard E.
1964. Effect of measures to improve humus form on the carbon and nitrogen balance of a soil. Ph.D. dissertation. Univ. Goettingen, Hann Muenden, Germany. (In German). 136 p.

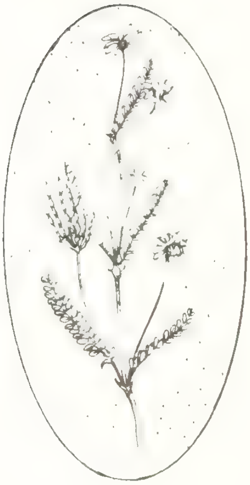
Pacific Northwest River Basins Commission Meteorology Committee.
1969. Climatological handbook, Columbia Basin States, precipitation. Vol. 2, 262 p. + appendices. Vancouver, Wash.

Peck, Dallas L., Allan B. Briggs, Herbert G. Schlicker, Francis G. Wells, and Hollis M. Dole.

1964. Geology of the central and northern parts of the Western Cascade Range in Oregon. Geol. Surv. Prof. Pap. 449, 59 p., illus. Washington, D.C.

United States Salinity Laboratory Staff.
1954. Diagnosis and improvement of saline and alkali soils. Agric. Handb. 60, 160 p. U.S. Dep. Agric., Washington, D.C.

Waddington, D. V.
1968. Effects of soil drainage on the growth of crownvetch. *In* Second crownvetch symposium, p. 44-47. Agron. Mimeogr. Penn. State Univ., University Park.



GPO 988-281

Miller, Richard E., and Ray Zalunardo.
1979. Long-term growth of eight legumes introduced at three forest locations in southwest Oregon. USDA For. Serv. Res. Pap. PNW-255, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Using nitrogen-fixing plants in forestry becomes financially more attractive as the costs of fertilizers and their application continue to increase. Eight legume cultivars were screened for suitability in Douglas-fir forests of southwest Oregon. The legumes were sown on concurrently fertilized and unfertilized plots within deer exclosures in three logged and burned clearcuts. Percent cover after the first and during the ninth growing season was clearly greater on 2- by 2-meter plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover but not subsequent plant cover or height. N fixation was not measured; however, all surviving species were nodulated.

KEYWORDS: Nitrogen fixation, leguminous plants, soil moisture, soil temperature, seeding (erosion control), fertilizer response (soil).

Miller, Richard E., and Ray Zalunardo.
1979. Long-term growth of eight legumes introduced at three forest locations in southwest Oregon. USDA For. Serv. Res. Pap. PNW-255, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Using nitrogen-fixing plants in forestry becomes financially more attractive as the costs of fertilizers and their application continue to increase. Eight legume cultivars were screened for suitability in Douglas-fir forests of southwest Oregon. The legumes were sown on concurrently fertilized and unfertilized plots within deer exclosures in three logged and burned clearcuts. Percent cover after the first and during the ninth growing season was clearly greater on 2- by 2-meter plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover but not subsequent plant cover or height. N fixation was not measured; however, all surviving species were nodulated.

KEYWORDS: Nitrogen fixation, leguminous plants, soil moisture, soil temperature, seeding (erosion control), fertilizer response (soil).

Miller, Richard E., and Ray Zalunardo.
1979. Long-term growth of eight legumes introduced at three forest locations in southwest Oregon. USDA For. Serv. Res. Pap. PNW-255, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Using nitrogen-fixing plants in forestry becomes financially more attractive as the costs of fertilizers and their application continue to increase. Eight legume cultivars were screened for suitability in Douglas-fir forests of southwest Oregon. The legumes were sown on concurrently fertilized and unfertilized plots within deer exclosures in three logged and burned clearcuts. Percent cover after the first and during the ninth growing season was clearly greater on 2- by 2-meter plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover but not subsequent plant cover or height. N fixation was not measured; however, all surviving species were nodulated.

KEYWORDS: Nitrogen fixation, leguminous plants, soil moisture, soil temperature, seeding (erosion control), fertilizer response (soil).

Miller, Richard E., and Ray Zalunardo.
1979. Long-term growth of eight legumes introduced at three forest locations in southwest Oregon. USDA For. Serv. Res. Pap. PNW-255, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Using nitrogen-fixing plants in forestry becomes financially more attractive as the costs of fertilizers and their application continue to increase. Eight legume cultivars were screened for suitability in Douglas-fir forests of southwest Oregon. The legumes were sown on concurrently fertilized and unfertilized plots within deer exclosures in three logged and burned clearcuts. Percent cover after the first and during the ninth growing season was clearly greater on 2- by 2-meter plots sown with alfalfa, crownvetch, and birdsfoot deervetch (trefoil) than with wetland deervetch, perennial lupine, annual lupine, flatpea, or hairy vetch. Fertilization influenced 1st-year cover but not subsequent plant cover or height. N fixation was not measured; however, all surviving species were nodulated.

KEYWORDS: Nitrogen fixation, leguminous plants, soil moisture, soil temperature, seeding (erosion control), fertilizer response (soil).

Un
St

Wa

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: *Pacific Northwest Forest and Range*
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

RESEARCH PAPER PNW-256

JULY 1979

GOVT. DOCUMENTS
DEPOSITORY ITEM

SEP 10 1979

CLEMSON
LIBRARY

CLEMSON UNIVERSITY LIBRARY
SEP 11 1979
SCI., TECH. & AGR. DIV.

Survival of Douglas-Fir Seedlings Sprayed with Atrazine, Terbacil, and 2,4-D

by H. Gratkowski,
R. Jaszkowski, and
L. Armstrong

FIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
DEPARTMENT OF AGRICULTURE FOREST SERVICE

Authors

H. GRATKOWSKI is Research Forester, Pacific Northwest Forest and Range Experiment Station, R. JASZKOWSKI is Silviculturist, Willamette National Forest, and L. ARMSTRONG is Silviculturist, Umpqua National Forest.

Survival of Planted Douglas-fir Seedlings Sprayed with Atrazine, Terbacil, and 2,4-D

eference Abstract

ratkowski, H., R. Jaszowski, and L. Armstrong.
1979. Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Grass control with atrazine increased survival of Douglas-ir seedlings when applied as a broadcast spray over new lantations on three summer-dry sites in southwestern Oregon. erbacil and 2,4-D were less effective than atrazine. Conifer urvival was excellent on four typical coastal sites in or ear the fog belt along the southwest Oregon coast.

EYWORDS: Herbicides (-regeneration, weed control (forest), atrazine, terbacil, 2,4-D, Douglas-fir, *Pseudotsuga menziesii*.

esearch Summary

esearch Paper PNW-256

979

Atrazine, 2,4,-D, and atrazine lus 2,4,-D were applied as broadast sprays to control grasses and orbs before conifer budbreak in ew Douglas-fir plantations. Grass ontrol did not increase survival r vigor of tree seedlings on four ool, moist sites in and near the og belt along the southwest Oregon oast. On three drier sites in the oast and Cascade Ranges, however, onifer survival on plots sprayed ith atrazine was double (48 percent) hat on plots without grass conrol (23 percent). Combining low volatile esters of 2,4-D with atrazine seems undesirable in broadcast sprays for grass and forb control in new plantations; Douglas-fir survival was less than on plots treated with the same amount of atrazine alone.

Both atrazine and terbacil effectively reduced grass cover the first summer after application, and a noticeable reduction was still evident early in the second summer. Terbacil, however, may have damaged the young Douglas-fir seedlings.

NTRODUCTION

Reforestation of sites occupied y grasses and forbs has long been silvicultural problem on forest and in western Oregon. Herbaceous lants use much of the available oil moisture, and many planted onifers cannot survive this intense ompetition during the first dry ummer seasons after planting. ortality is greatest on dry inland ites east of the crest of the oast Ranges.

On most sites, atrazine at a rate f 4 pounds active ingredient per cre (4.5 kg/ha) provides excellent rass control without damaging small ouglas-fir seedlings. Unfortunately, trazine does not kill many broad-eaf weeds. As a result, atrazine as often released broadleaf weeds s well as trees, reducing survival nd growth of the young conifers.

To control broadleaf weeds as well s grasses, low volatile esters of ,4-D have been added to atrazine prays (Newton 1970), but several oresters indicated that this com-ination may have damaged newly lanted conifers on some areas. This roblem was studied in 1971. The ombination of atrazine and 2,4-D was ested to determine its effect on urvival and vigor of Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco) eedlings when broadcast sprayed on ew plantations.

TUDY AREAS AND METHODS

Seven areas were selected for reatment: five on the Siskiyou ational Forest in and near the fog elt on the coastal (western) slope f the Coast Ranges; two on drier ites east of the crest of the Coast Ranges. Four of the coastal sites were typical of most sites on the lower west slopes of the Coast Ranges. One coastal site near the Rogue River, however, was a droughty, dry site with vegetation similar to that of the dry interior valleys between the Coast and Cascade Ranges: second growth Douglas-fir was interspersed with oak (*Quercus* sp.), Pacific madrone (*Arbutus menziesii* Pursh), grassy balds, and rock outcrops. The other two dry sites were inland at an elevation of 2,800 ft (853 m) above sea level on the western slope of the Cascade Range in the Umpqua National Forest (fig. 1). All sites were in cutover areas occupied by mixtures of grasses and forbs with few woody plants.

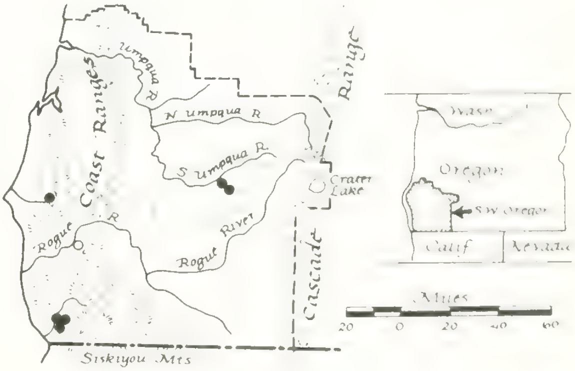


Figure 1.--Location of the seven study areas.

Rainfall on the coastal sites averages from 70 to more than 100 in (178 to 254 cm) per year, and cold, coastal fog periodically cools the environment and reduces drought effects even during summer. Rainfall on the west slope of the Cascade Range where the inland plots are located averages about 45 to 50 in (114 to 127 cm) per year, but summer drought is much more severe.

NTRODUCTION

Reforestation of sites occupied y grasses and forbs has long been silvicultural problem on forest and in western Oregon. Herbaceous lants use much of the available oil moisture, and many planted onifers cannot survive this intense ompetition during the first dry ummer seasons after planting. ortality is greatest on dry inland ites east of the crest of the oast Ranges.

On most sites, atrazine at a rate f 4 pounds active ingredient per cre (4.5 kg/ha) provides excellent rass control without damaging small ouglas-fir seedlings. Unfortunately, trazine does not kill many broadeaf weeds. As a result, atrazine as often released broadleaf weeds s well as trees, reducing survival nd growth of the young conifers.

To control broadleaf weeds as well s grasses, low volatile esters of ,4-D have been added to atrazine prays (Newton 1970), but several oresters indicated that this comination may have damaged newly lanted conifers on some areas. This roblem was studied in 1971. The ombination of atrazine and 2,4-D was ested to determine its effect on urvival and vigor of Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco) eedlings when broadcast sprayed on ew plantations.

TUDY AREAS AND METHODS

Seven areas were selected for eatment: five on the Siskiyou tional Forest in and near the fog lt on the coastal (western) slope the Coast Ranges; two on drier tes east of the crest of the Coast Ranges. Four of the coastal sites were typical of most sites on the lower west slopes of the Coast Ranges. One coastal site near the Rogue River, however, was a droughty, dry site with vegetation similar to that of the dry interior valleys between the Coast and Cascade Ranges: second growth Douglas-fir was interspersed with oak (*Quercus* sp.), Pacific madrone (*Arbutus menziesii* Pursh), grassy balds, and rock outcrops. The other two dry sites were inland at an elevation of 2,800 ft (853 m) above sea level on the western slope of the Cascade Range in the Umpqua National Forest (fig. 1). All sites were in cutover areas occupied by mixtures of grasses and forbs with few woody plants.

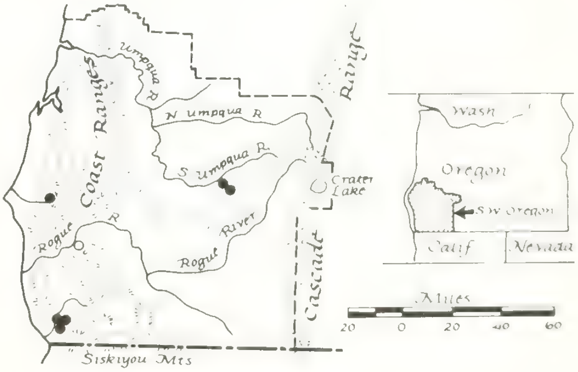


Figure 1.--Location of the seven study areas.

Rainfall on the coastal sites averages from 70 to more than 100 in (178 to 254 cm) per year, and cold, coastal fog periodically cools the environment and reduces drought effects even during summer. Rainfall on the west slope of the Cascade Range where the inland plots are located averages about 45 to 50 in (114 to 127 cm) per year, but summer drought is much more severe.

The study was designed as a randomized complete block experiment with one complete set of treatments on each of seven sites (fig. 1). On each site, five 21- x 105-ft (6.4- x 32.0-m) plots were planted with 125 2-0 Douglas-firs during late February and early March. After planting, four plots received one of four spray treatments; the fifth plot was left unsprayed as a control. A total of 4,375 trees were included in the experiment; 875 trees in the seven plots that received each spray treatment and a similar number in the unsprayed control plots.

Three herbicides and one combination of chemicals were applied as broadcast sprays over the conifers and competing vegetation (table 1). The chemicals were:

atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine
2,4-D	(2,4-dichlorophenoxy) acetic acid
terbacil	3-tert-butyl-5-chloro-6-methyluracil

Table 1--Treatments included in each replication

Treatment	Chemical		
	Atrazine	2,4-D	Terbacil
	- - - -Pounds per acre[1]- - - - -		
none	[2]0	0	0
Atrazine	4	0	0
2,4-D	0	1-1/2	0
Atrazine + 2,4-D	4	1-1/2	0
Terbacil	0	0	2

[1] Pounds active ingredient per acre for atrazine and terbacil; pounds acid equivalent for 2,4-D.

[2] 1 lb/acre = 1.12 kg/ha.

Because both atrazine and terbaci are soil-active herbicides primar absorbed through roots of suscept species, all sprays were applied during the period from mid-March through early April 1971, when su ficient rain could be expected a application to leach the chemical into the soil. Weather condition after treatment were normal: approximately 6.5 in (16.5 cm) of rain fell on the sprayed plots in the Cascade Range after treatment, followed by an extremely dry July August, and early September.

All areas were examined during early June 1971, 2 months after treatment, to rate degree of gras and forb control, to record tree survival, and to note initial effects of the sprays on condition the Douglas-fir seedlings before the beginning of the first summer drought period. A second examination was made in October 1971 to determine survival and vigor of the small conifers at the end of the first summer. A third examination was made in June 1972 to rate residual effects of the sprays on grasses and forbs--effe that might increase survival of the young conifers during the sec dry summer season. A final exami nation was made in October 1972 t determine survival and vigor of the conifers at the end of the second summer.

RESULTS

Grass control does not seem ne sary to establish Douglas-fir plantations in typical cool, mois habitats within or near the fog b along the southwest Oregon coast during years when normal climatic conditions occur. Sprays to cont grasses and forbs did not increas survival or improve vigor of newly planted Douglas-firs on the four typical coastal sites (table 2). On such sites, therefore, expenditures for grass and forb control can be a waste of time, energy, and money. On coastal sites with shallow soils and limited soil moisture storage capacity, however, and on all inland sites, where summer drought is more severe, grass control is necessary to insure survival of young Douglas-firs planted in grass-forb communities.

Because grass and forb control did not improve survival or vigor of small Douglas-firs in the four plantations on cool, moist, coastal sites, evaluation of the chemicals can only be based upon their effectiveness on the three dry sites: two in the Cascade Range, and one droughty site deep within the Coast Ranges. Survival of Douglas-fir seedlings at the end of the second summer on the dry sites was far less than survival on typical coastal sites ($F_{1/5}$ = 207.726, P<0.001).

Survival of Douglas-firs planted in untreated grass-forb plots was extremely low on the dry sites. The trees withstood and survived initial transplant shock and springtime environmental stresses very well, for survival and vigor of the conifers was good on all three areas in June before onset of the first summer drought. But only 45 percent of the trees survived the first summer, and only 23 percent were alive at the end of the second summer. In addition, most trees that survived in untreated plots were noticeably weakened and low in vigor after the second summer drought.

On the three dry sites, chemical sprays that reduced grass and forb competition appreciably increased Douglas-fir survival. Although the difference was not significant at the 5-percent level of probability in this small sample (t_2 = 2.681, P>0.05), atrazine at a rate of 4 pounds active ingredient per acre (4.5 kg/ha) seems the most effective broadcast spray for application over freshly planted Douglas-fir seedlings. Survival percentages for the three dry sites were:

Area	Atrazine	No spray
4	42	25
6	62	19
7	38	24

At the end of the second summer, 48 percent of the trees were alive on atrazine-sprayed plots; only 23 percent survived in the unsprayed control plots. In addition, far more trees were healthy and vigorous on atrazine-sprayed plots.

No other chemical spray was as effective as atrazine in this experiment. Fewer trees survived on plots sprayed with low volatile esters of 2,4,-D or atrazine combined with 2,4-D. Survival on terbacil-treated plots was also less than that on atrazine-treated plots.

Three treatments: (1) atrazine, (2) atrazine plus 2,4-D, and (3) terbacil provided good grass control throughout the first summer after spraying, and grass control was still readily evident at the beginning of the second summer (table 3). Atrazine combined with 2,4-D also appreciably reduced the forb cover the first summer after spraying. Terbacil was less effective on forbs the first summer, but some residual forb-control was still evident at the beginning of the second summer.

Table 2--Survival and condition of Douglas-fir seedlings after one application of herbicides for grass and forb control

Survival and condition	Beginning of summer[1]					End of summer[2]					End of second summer[2]				
	Control	Atrazine	2,4-D	Atrazine + 2,4-D	Terbacil	Control	Atrazine	2,4-D	Atrazine + 2,4-D	Terbacil	Control	Atrazine	2,4-D	Atrazine + 2,4-D	Terbacil
								Percent							
								COOL COASTAL SITES							
Survival	99	99	99	97	97	92	90	92	91	89	88	86	87	88	87
Condition															
Healthy	83	79	78	78	72	87	78	80	78	80	86	79	82	81	84
Weak	16	20	20	18	24	5	12	12	13	9	2	7	5	7	3
Dead	1	1	2	4	4	8	10	8	9	11	12	14	13	12	13
								DRY INLAND SITES							
Survival	96	94	96	93	93	45	70	51	59	62	23	48	32	34	37
Condition															
Healthy	72	74	68	59	66	24	51	30	33	38	10	29	14	18	23
Weak	24	20	28	33	24	21	19	21	26	24	13	19	18	16	14
Dead	4	6	4	8	10	55	30	49	41	38	77	52	68	66	63

[1] Survival data for all trees on each site; condition data for 40 percent of the trees at beginning of first summer.

[2] Survival and condition data for all trees at end of first and second summer.

Table 3--Grass and forb control after one application of herbicides in southwestern Oregon

Chemicals	Rate per acre	Grass control			Forb control		
		Spring 1971	Fall 1971	Spring 1972	Spring 1971	Fall 1971	Spring 1972
	Pounds[1/]	Percent control					
COASTAL SITES							
Control	0	0	0	0	0	0	0
Atrazine	4	90	89	2	1	6	3
Atrazine + 2,4-D	4 + 1½	84	83	11	16	19	0
2,4-D	1½	0	0	0	7	7	0
Terbacil	2	73	73	28	1	19	1
INLAND SITES							
Control	0	0	0	0	0	0	0
Atrazine	4	74	71	37	7	10	0
Atrazine + 2,4-D	4 + 1½	75	76	20	69	63	0
2,4-D	1½	0	0	0	3	3	0
Terbacil	2	65	68	54	14	21	15

[1/] Pounds active ingredient per acre for atrazine and terbacil; pounds acid equivalent for 2,4-D. All chemicals were applied in water carriers.

DISCUSSION

Excellent survival of Douglas-fir seedlings planted in untreated grass and forb communities in and near the fog zone indicates that grass and forb control may not be necessary on typical coastal sites. Summer drought conditions are probably less severe than on inland sites. Adequate soil moisture storage, a high percentage of overcast days, and periodic fog evidently interact to reduce moisture stress in freshly planted tree seedlings. Stone (1957) showed that artificial dew (spray) increased the length of time ponderosa pine (*Pinus ponderosa* Laws.), incense-cedar (*Libocedrus decurrens* Torr.), and white fir (*Abies concolor* (Gord. and Glend.) Lindl.) survived after soil moisture had been depleted to the ultimate wilting point of sunflower. Cool coastal fog may have a similar effect and reduce moisture stress in Douglas-fir seedlings.

On the three dry sites, survival of Douglas-fir seedlings sprayed with 2,4-D or with a combination of 2,4-D and atrazine was less than survival of trees sprayed with atrazine alone. This strongly suggests that broadcast sprays of 2,4-D have an adverse effect on newly planted Douglas-fir seedlings experiencing transplant shock on summer-dry sites. On such sites, young Douglas-firs must also endure severe drought stress as well. The herbicidal effect of 2,4-D is evidently sufficient to tip the balance from survival to death for many trees on dry sites.

Better established trees in older plantations evidently can withstand any adverse effects of 2,4-D. In an earlier study (Gratkowski 1976) established Douglas-firs survived broadcast sprays of 3 lb active ingredient of atrazine plus 1/2 lb acid equivalent of 2,4-D per acre (3.4 kg atrazine plus 0.6 kg 2,4-D per ha).

In contrast to effects on established seedlings, the data from dr sites indicate that terbacil may damage freshly planted Douglas-fir seedlings. Although terbacil provided appreciable grass and forb control for two summers, survival of Douglas-fir seedlings was less than that obtained with atrazine. Herbicidal activity of terbacil has also been reported to vary wit differences in soil type (Kratky and Warren 1973, Stewart and Beebe 1974). This variation further complicates silvicultural use of terbacil and favors use of atrazin in broadcast sprays for grass control in new plantations of Douglas fir.

CONCLUSIONS

An important result of this stu is the strong indication that gras control is not usually needed to establish Douglas-fir plantations in grass-forb communities at low elevations on the western slope of the Coast Ranges in southwest Oreg Under normal climatic conditions, environmental stress--especially summer drought--is evidently ameliorated by fog on forest sites in and near the fog belt along the Oregon coast. On drier inland are where summer drought is more sever and even on droughty sites in the Coast Ranges, grass control is needed to insure survival of new Douglas-fir plantations. Almost ll forest areas east of the crest f the Coast Ranges can be conidered dry sites.

On dry sites, herbicidal sprays roadcast over the trees, grasses, nd forbs in new Douglas-fir plantaions effectively controlled grasses nd increased survival of the tree eedlings. A more advisable procedure, owever, would be to use the herbicide, or site preparation *before* planting. amage to the small, susceptible onifers would be minimized if spray olutions were not allowed to fall n their foliage.

Atrazine applied in a water carier at a rate of 4 lb active inredient per acre (4.5 kg/ha) was he most effective treatment after lanting on the three drier areas n this study. Atrazine provided xcellent grass control and resulted n best survival of Douglas-fir eedlings at the end of the second ummer after planting. Survival on trazine-sprayed plots was more than ouble that of trees in untreated ontrol plots (48 percent vs. 3 percent).

Results of this experiment strongly uggest that low volatile esters of ,4-D should not be added to atrazine n broadcast sprays to control forbs n new plantations of Douglas-fir on orest sites east of the crest of the oast Ranges. This combination of erbicides (probably the 2,4-D comonent) may have damaged or killed eaker trees that were suffering ransplant shock and environmental tress during the dry summer season. arly spring application of atrazine lone at a rate of 4 pounds active ngredient per acre is a far better reatment.

LITERATURE CITED

Gratkowski, H.
1976. Herbicides for grass and forb control in Douglas-fir plantations. USDA For. Serv. Res. Note PNW-285, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Kratky, B. A., and G. F. Warren.
1973. Water-soil-plant interactions with terbacil. Weed Sci. 21:451-454.

Newton, Michael.
1970. Herbicides in forestry. *In* Oregon Weed Control Handbook, Coop. Ext. Serv., Oreg. State Univ., Corvallis, Oreg., p. 232.

Stewart, R. E., and T. Beebe.
1974. Survival of ponderosa pine seedlings following control of competing grasses. *In* Proc. West. Soc. Weed Sci. 27:55-58.

Stone, Edward C.
1957. Dew as an ecological factor. I-II. The effect of artificial dew on the survival of *Pinus ponderosa* and associated species. Ecology 38(3):407-422.

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: All recommendations for operational uses of pesticides were registered for such uses by the Federal Environmental Protection Agency at the time of this publication. Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

PROTECT

Use Pesticides Safely
FOLLOW THE LABEL
U.S. DEPARTMENT OF AGRICULTURE

Gratkowski, H., R. Jaszkowski, and L. Armstrong.
1979. Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Grass control with atrazine increased survival of Douglas-fir seedlings when applied as a broadcast spray over new plantations on three summer-dry sites in southwestern Oregon. Terbacil and 2,4-D were less effective than atrazine. Conifer survival was excellent on four typical coastal sites in or near the fog belt along the southwest Oregon coast.

KEYWORDS: Herbicides (-regeneration, weed control (forest), atrazine, terbacil, 2,4-D, Douglas-fir, *Pseudotsuga menziesii*.

Gratkowski, H., R. Jaszkowski, and L. Armstrong.
1979. Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Grass control with atrazine increased survival of Douglas-fir seedlings when applied as a broadcast spray over new plantations on three summer-dry sites in southwestern Oregon. Terbacil and 2,4-D were less effective than atrazine. Conifer survival was excellent on four typical coastal sites in or near the fog belt along the southwest Oregon coast.

KEYWORDS: Herbicides (-regeneration, weed control (forest), atrazine, terbacil, 2,4-D, Douglas-fir, *Pseudotsuga menziesii*.

Gratkowski, H., R. Jaszkowski, and L. Armstrong.
1979. Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Grass control with atrazine increased survival of Douglas-fir seedlings when applied as a broadcast spray over new plantations on three summer-dry sites in southwestern Oregon. Terbacil and 2,4-D were less effective than atrazine. Conifer survival was excellent on four typical coastal sites in or near the fog belt along the southwest Oregon coast.

KEYWORDS: Herbicides (-regeneration, weed control (forest), atrazine, terbacil, 2,4-D, Douglas-fir, *Pseudotsuga menziesii*.

Gratkowski, H., R. Jaszkowski, and L. Armstrong.
1979. Survival of planted Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Grass control with atrazine increased survival of Douglas-fir seedlings when applied as a broadcast spray over new plantations on three summer-dry sites in southwestern Oregon. Terbacil and 2,4-D were less effective than atrazine. Conifer survival was excellent on four typical coastal sites in or near the fog belt along the southwest Oregon coast.

KEYWORDS: Herbicides (-regeneration, weed control (forest), atrazine, terbacil, 2,4-D, Douglas-fir, *Pseudotsuga menziesii*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Research Paper JULY 1979
PNW-257

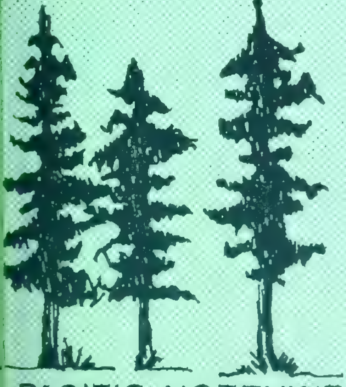
CLEMSON UNIVERSITY LIBRARY
OCT 19 1979
SCI., TECH. & AGR. DIV.

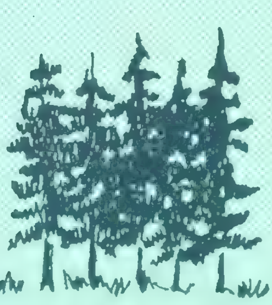
GOVT. DOCUMENTS
DEPOSITORY ITEM
OCT 5 1979
CLEMSON
LIBRARY

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY ON DOUGLAS-FIR

REPORT NO. 5

THE HOSKINS STUDY, 1963-1975





PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Abstract for Report No. 1

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock which is established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and Vancouver Island, Canada. Site quality of these areas varies from I through IV.

Climatic and soil characteristics for each area and data for the stand after the conditioning thinning are described briefly.

KEYWORDS: Thinnings, stand growth, Douglas-fir, *Pseudotsuga menziesii*.

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY ON DOUGLAS-FIR

Report No. 5—The Hoskins Study, 1963-1975

by

Alan B. Berg, Professor
School of Forestry, Oregon State University

and

John F. Bell, Professor
School of Forestry, Oregon State University

USDA Forest Service Research Paper PNW-257

Pacific Northwest Forest and Range Experiment Station
Forest Service
U.S. Department of Agriculture
Portland, Oregon
1979

Other LOGS (levels-of-growing-stock) reports:

WILLIAMSON, RICHARD L., and GEORGE R. STAEBLER.
1965. A cooperative level-of-growing-stock study in Douglas-fir. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., 12 p., illus. Portland, Oreg.

Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

WILLIAMSON, RICHARD L., and GEORGE R. STAEBLER.
1971. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 1--Description of study and existing study areas. USDA For. Serv. Res. Pap. PNW-111, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

BELL, JOHN F., and ALAN B. BERG.
1972. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 2--The Hoskins study, 1963-1970. USDA For. Serv. Res. Pap. PNW-130, 19 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

DIGGLE, P. K.
1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (Report No. 3, Cooperative L.O.G.S. Study Series). Can. For. Serv. Inf. Rep. BC-X-66, 46 p., illus. Pac. For. Res. Cent., Victoria, B.C.

WILLIAMSON, RICHARD L.
1976. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 4--Rocky Brook, Stampede Creek, and Iron Creek. USDA For. Serv. Res. Pap. PNW-210, 39 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The U.S. Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

Reference Abstract

Berg, Alan B., and John F. Bell.
1979. Levels-of-Growing-Stock Cooperative Study on Douglas-fir: Report No. 5--The Hoskins Study, 1963-1975. USDA For. Serv. Res. Pap. PNW-257, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Growth data are presented for the first 12 years of management of a young Douglas-fir stand in the Oregon Coast Ranges manipulated to include eight levels of growing stock. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

KEYWORDS: Growing stock (-increment/yield, thinnings, Douglas-fir, *Pseudotsuga menziesii*.

RESEARCH SUMMARY

Research Paper PNW-257

1979

A regional cooperative study of the influence of levels of growing stock on stand growth was initiated in 1962. The School of Forestry, Oregon State University, maintains one of the nine study areas. The Hoskins study was established in 1963 in a 20-year-old Douglas-fir stand of natural origin and site class II.

Suppression mortality on the control plots has reduced the number of trees per acre from 1,727 in 1963 to 938 in 1975. There has been little mortality on thinned plots.

There was significantly more cubic-foot volume in trees of 11.6-inch diameter and larger for all treatments than for the control plots. All treatments except 1 and 2, the lowest levels of growing stock, had more cubic-foot volume in trees 9.6 inches and larger than the control plots did. In trees 7.6 inches and larger, however, cubic-foot volume for treatment 7--the highest level of growing stock--was approximately equal to the control plots; but all other treatments had less volume. Although the control plots have much more total cubic-foot volume, this additional volume is contained in the 639 trees (68 percent of the total) that are less than 7.6-inch d.b.h. In all probability, most of the mortality will occur in these size classes over the next few years. Also, the trees in thinned plots are growing at a much faster rate than the trees in control plots.

Treatments 7 and 8 have more board-foot volume than the controls, but the difference in board-foot volume between treatments 4, 5, and 6 and the controls is not great. Of special interest is treatment 4 which now has more board-foot volume in trees 11.6 inch d.b.h. and larger than the control plots have in trees 9.6 inches and larger. As the growing stock in treatment 4 increases with time, board-foot volumes could exceed those of the control and possibly of treatment 7.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during subsequent treatment periods.

Contents

INTRODUCTION 1

METHODS. 3

RESULTS AND DISCUSSION 3
  Second Treatment Period. 3
  Third Treatment Period 4

DISCUSSION, ALL TREATMENT PERIODS, 1963-75 . . . 7

APPENDIX 1 11
  Description of Experiment. 11
  Experimental Design. 11
  Crop Tree Selection. 11
  Initial or "Calibration" Thinning. 11
  Treatments 11
  Control of Thinning Interval 12
  Control of Type of Thinning. 12

APPENDIX 2 12
  Calculating Cumulative Yield, Tables 4 and 5 . 12

TABLES (See listing) 13

Tables

Table 1--Average height of crop trees by treatment and year 13

Table 2--Stand data for all live trees in English units, at beginning and end of periods, by treatment. 14

Table 2A--Stand data for all live trees in metric units, at beginning and end of periods, by treatment 15

Table 3--Stand data for crop trees at beginning and end of treatment periods, by treatment 16

Table 4--Gross periodic annual growth, total growth, and cumulative volume yield, in English units, for all trees, by treatment period 17

Table 4A--Gross periodic annual growth, total growth, and cumulative volume yield, in metric units, for all trees, by treatment period 18

Table 5--Gross periodic annual growth and cumulative volume yield for crop trees, by treatment and treatment period. 19

Table 6--Periodic annual mortality of all trees, by treatment and treatment period 20

Table 7--Basic data by treatment and plot for all live trees 1971-75 (second and third treatment periods). 21

Table 8--Basic data by treatment and plot for crop trees (second and third treatment periods), 1971-75 22

Table 9--Stand table after second treatment thinning, 1970. 23

Table 10--Trees removed at beginning of the second and third treatment periods, 1970 and 1973 24

Table 11--Stand table at end of second treatment period, 1973 25

Table 12--Periodic annual net increment data for all trees by treatment and thinning period. 26

Table 13--Stand table after third treatment thinning, 1973. 27

Table 14--Stand table at end of third treatment period, 1975. 28

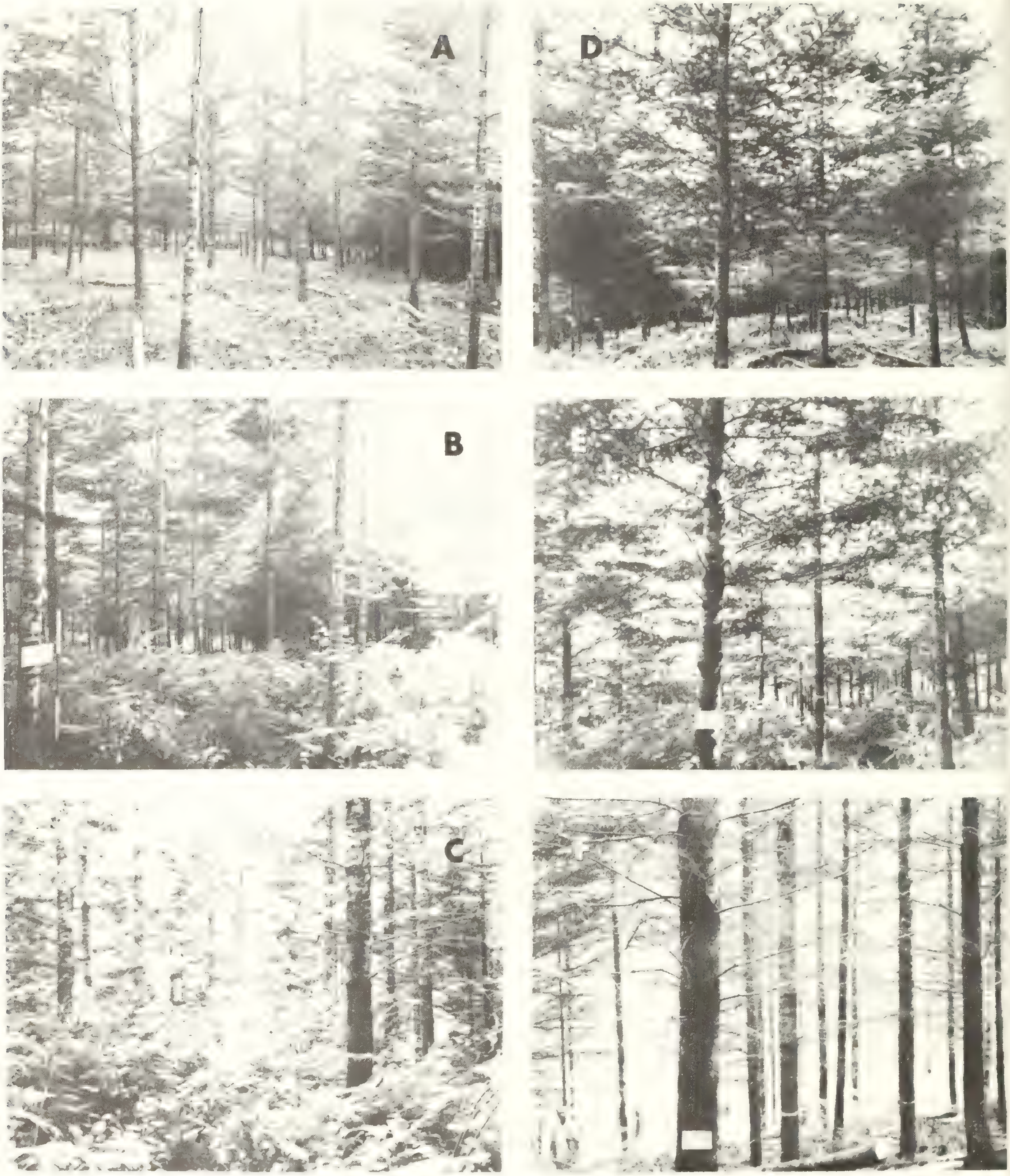


Figure 1.--Treatment 1, plot 8: *A*, 1963; *B*, 1966; *C*, 1976. Treatment 7, plot 19: *D*, 1963; *E*, 1966; *F*, 1976.

Introduction

This is one of a series of reports on a cooperative levels-of-growing-stock study on Douglas-fir in the Pacific Northwest designed to examine the effect of different levels of growing stock on wood production, tree size, and growth-growing stock ratios.

Report No. 1 presented the study plan, including analysis of data and description of installations. Report No. 2 covered the Hoskins study for the calibration period (1964-66) and the first treatment period (1967-70). This report covers the second (1971-73) and third (1974-75) treatment periods and includes summary data from the calibration and first treatment periods (see fig. 1 for pictorial comparison of plot 8 and plot 19 for 1963, 1966, and 1976).

The Hoskins study area is located approximately 22 miles west of Corvallis near Hoskins, Oregon, on land owned by Starker Forests. The area is immediately east of the summit of the Coast Ranges (fig. 2) on a southern aspect with slopes from 15 to 55 percent. At the time the study was established (1963), the stand was 14 years of age at breast height (total age, 20 years) and contained an average of 1,727 trees per acre (fig. 3). The study area is site II. The stand is of natural origin following wildfires.

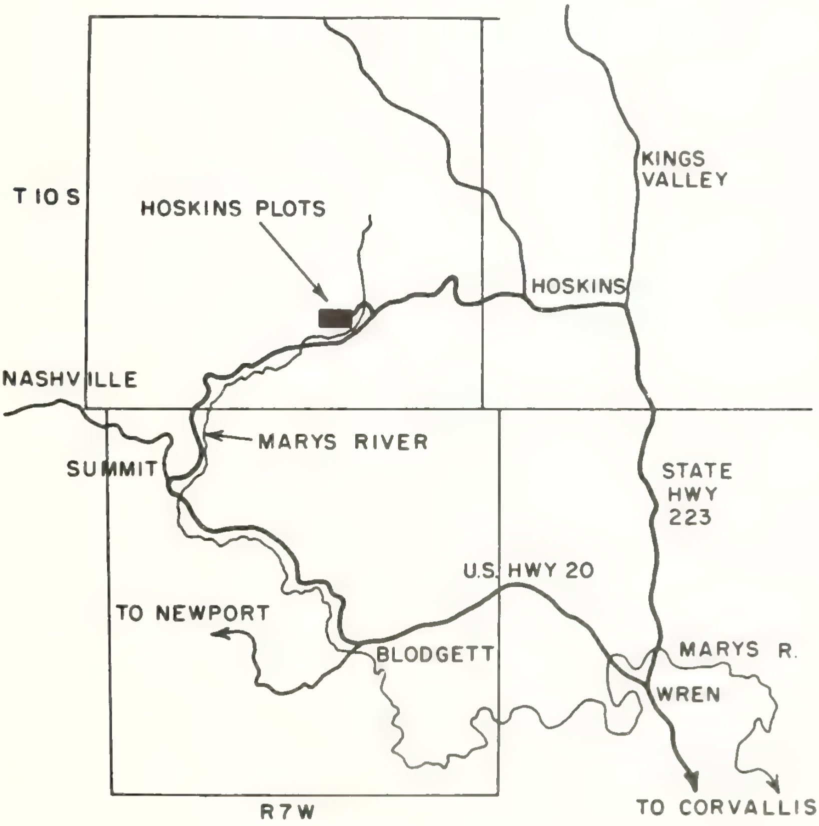


Figure 2.--Location of the Hoskins study.

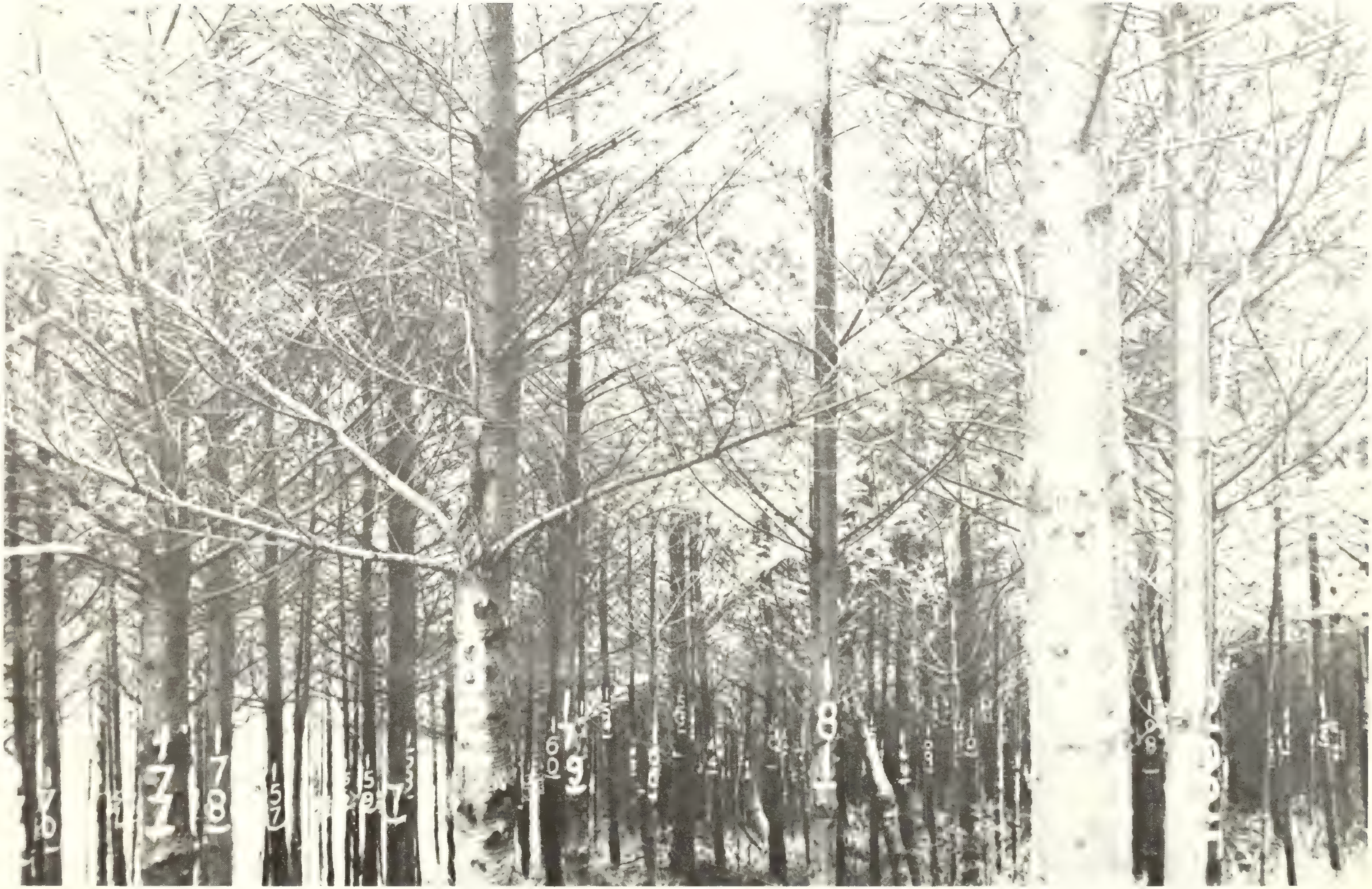


Figure 3.--Plot 22 (control) in 1963. Crop trees have a white circumferential band painted at the point of measurement. Noncrop trees have a different color band for each treatment and identifying numbers of corresponding color. This facilitates work in the plots and identifies treatments for observers.

Methods[1]

During the summer of 1963, 27 plots, 1/5-acre in size, were established (fig. 4). Initial density was controlled by a calibration thinning to a prescribed level of basal area. The d.b.h. of each tree has been measured to the nearest 0.1 inch at the end of each growing season. Total height of selected trees was measured at the end of the 1963, 1966, 1970, 1973, and 1975 growing seasons (table 1). Thinnings were made when the height of the crop trees increased by 10 feet. Thus, thinnings were made when the height of the crop trees increased by 10, 20, 30, 40 feet, etc. Height growth (13.1 feet) during the first treatment period, however, exceeded this because the plots were not thinned for 4 years. This irregularity in relation of height growth to thinning interval was corrected in the third treatment period which reduced the period to two growing seasons (1974-75).

Results and Discussion

SECOND TREATMENT PERIOD

The second treatment period was three growing seasons (1971-73). The stand table at the beginning of the second treatment period is presented in table 9 and at the end of the period in table 11. Data for the trees removed during the second thinning are presented in table 10. Only one tree per acre per year died on treatments 2 and 5 compared with 62 trees per acre per year on the control plots (table 6).

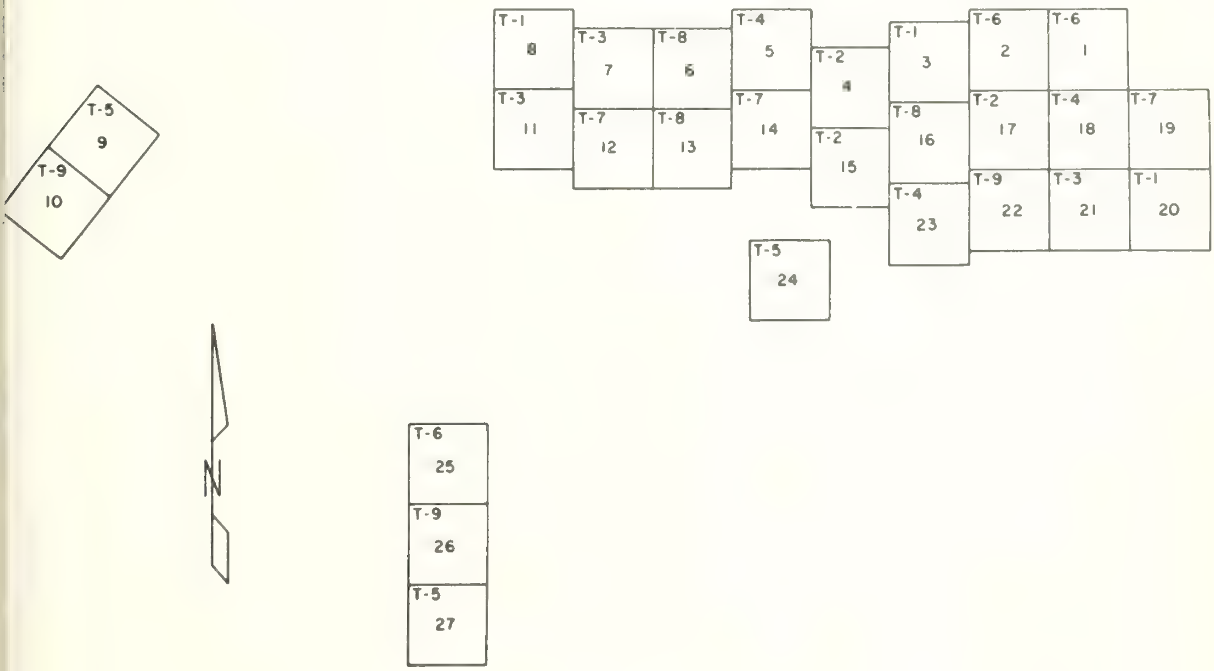


Figure 4.--Layout of Hoskins levels-of-growing-stock study. The plots are one-fifth acre in size.

---

[1] The treatment schedule is found on the inside front cover. See Reports 1 and 2 for additional details. Other LOGS reports are listed on the back of the title page.

All Live Trees

The basic data for all live trees (crop[2] and noncrop) for each treatment by growing season are shown in table 2. The table shows the wide range in basic data among the various treatments and the control. For instance, at the end of the second treatment period, the total number of trees per acre varied from 118 to 1,087 and the quadratic mean d.b.h. from 6.6 to 11.8 inches. Basal area per acre varied from 85.1 to 256.3 square feet and total volume per acre from 2,303 to 6,955 cubic feet.

The spread in quadratic mean diameter between treatments and control continues to widen. Most of this increase is due to growth because the quadratic mean diameter before and after each thinning are nearly the same.

Total volume in cubic feet varies according to stand density in either number of trees or basal area--the higher the density, the greater the volume.

The gross periodic annual increment[3] (PAI) and cumulative volume yield (see appendix 2 for calculation procedures) for all trees are given in table 4. The cumulative volume yield data do not include the volume removed during the calibration thinning. The volume removed, however, was estimated to be 1,238 cubic feet per acre--the difference between the average volume of the eight treatments and the control (table 2). The diameter PAI varied from 0.42 inch to 0.62 inch on treatment plots compared with 0.15 inch for the control plots. The basal area and cubic-foot volume increment among the eight treatments was largest for treatment 7 and smallest for treatment 1. The gross basal area increment of the control plots was greater than that of any of the treatments for the 1971 growing season. For the 1973 growing season, the gross basal area increment for treatment 7 was greater than that for the control plots; yet the total basal area per acre of the live trees was 148.7 and 247.4 square feet for treatment 7 and the control plots at the beginning of the 1973 growing seaso The gross PAI for the second treatment period varied from 293 cubic feet per acre for treatment 1 to 583 cubic feet for the control plots. The basic stand data by treatment and plot for all live trees are shown in table 7.

Crop Trees

The stand data by treatment for the crop trees are given in table 3. At the end of the second treatment period (1973), the cubic-foot volume of the crop trees in the treatment plots was 1.6 to 1.9 times that of the crop trees in the control plots.

The crop tree increment data are shown in table 5. The basal area increment of the crop trees for the secon treatment period for the thinned plots was 2.2 to 3.5 times greater than the basal area increment of the crop trees on the control plots. Of greater significance is that the PAI in cubic feet for the crop trees in the thinned plots is from 2.1 to 2.8 times that of crop trees in the controls.

The basic data for the crop trees by treatment and plot for the second treat ment period are found in table 8.

THIRD TREATMENT PERIOD

The third treatment period was two growing seasons (1974-75) (see "Methods Data for the trees removed during the third treatment period are presented in table 10. The stand table at the beginning of the third treatment period is given in table 13 and at the end of the period in table 14. Only one tree per acre per year died on treatments 5, 7, and 8 compared with 74 trees per acre per year on the control plots (table 6).

---

[2] An effort was made to designate well-formed, uniformly spaced, dominant trees at the rate of 80 per acre as crop trees prior to calibration thinning.

[3] Increment and growth are used synonymously in this report.

All Live Trees

The basic data for all live trees (crop and noncrop) during the third period for each treatment by year are given in table 2. At the end of the third treatment period, the total number of trees per acre varied from 83 to 938 and the average d.b.h. from 7.1 to 13.2 inches. Basal area per acre varied from 77.0 to 261.0 square feet and total volume per acre from 2,192 to 7,508 cubic feet. Treatment 1 has less basal area and cubic-foot volume at the end of the third treatment period than at the end of the second period because of the continued heavy thinnings called for in the study plan.

The spread in average diameter between treatments and the control continued to widen. Total volume in cubic feet varied according to stand density in either number of trees or basal area--the higher the density, the greater the volume.

The gross PAI and cumulative volume yield (see appendix 2 for calculation procedures) for all trees is given in table 4. The diameter PAI varied from 0.33 to 0.56 inch on treatment plots compared with 0.11 inch for the control plots. The basal area and cubic-foot volume increment among the eight treatments were largest for treatment 7 and smallest for treatment 1. Treatments 5, 6, 7, and 8 had a larger gross basal area PAI than the control plots (table 4). The gross basal area PAI per acre for treatment 7 for the third treatment period was 10.0 square feet compared with 8.8 for the control plots; yet the total basal area of the live trees was 150.0 and 256.3 square feet at the beginning of the 1974 growing season for treatment 7 and the control plots, respectively.

The gross PAI per acre for the third treatment period varied from 223 cubic feet for treatment 1 to 437 for treatment 7 compared with 440 cubic feet for the control plots.

Figure 5 gives the cumulative cubic-foot volume by treatments for 1975 for trees larger than 11.5, 9.5, 7.5, 5.5, and 3.5-inch d.b.h. Trees 12 inches and larger in the treatment plots had significantly more volume than trees in the control plots. Trees in all treatments except 1 and 2 had more cubic-foot volume in trees 10 inches and larger than did trees in the control plots. Volume of trees 8 inches and larger in treatment 7, however, was approximately equal to that of the control plots, but trees in all other treatments had less volume. Although the control plots have much more total cubic-foot volume, this additional volume is contained in the 639 trees (68 percent of the total) that are less than 7.6-inch d.b.h. (table 14). Most of the mortality will probably occur in these size classes over the next few years. Also, trees in the thinned plots are growing at a much faster rate than the trees in control plots. This could mean that the volumes in at least some of the thinned plots in the next treatment periods will equal or surpass those of the control plots.

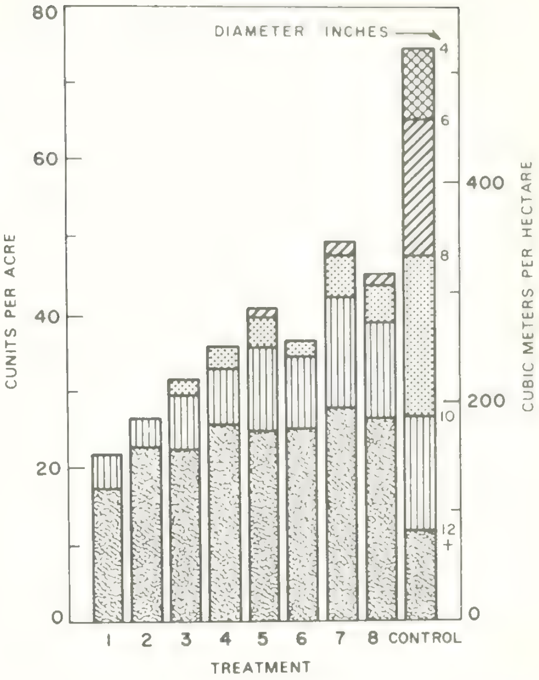


Figure 5.--Cumulative 1975 cubic-foot volumes for trees larger than 11.6-, 9.6-, 7.6-, 5.6-, and 3.6-inch d.b.h. by treatments; a cunit is 100 cubic feet.

Figure 6 shows the cumulative 1975 Scribner board-foot volumes for trees larger than 11.5-, 9.5-, and 7.5-inch d.b.h., all to a 6-inch top diameter. Only in treatments 7 and 8 did trees 7.6-inch d.b.h. and larger have more total board-foot volume than trees in the control plots. Trees 9.6-inch d.b.h. and larger, however, in all treatments except treatment 1 have more volume; and trees 11.6-inch d.b.h. and larger in all treatments have a larger board-foot volume than trees in the controls.

This further emphasizes the greater volume in the larger tree sizes in the treatment trees over those in the control plots. Trees in treatments 7 and 8 have more board-foot volume than trees in the controls, but the difference in volume between treatments 4, 5, and 6 and the controls is not great. Of special interest is treatment 4 which now has more board-foot volume in trees 11.6 inches and larger than the control plots have in trees 9.6 inches and larg
As the growing stock in treatment 4 increases with time, the board-foot volumes could exceed those of the control and possibly of treatment 7.

In figure 7 the Scribner board-foot volume thinned in 1966, 1970, and 1973 are added to the 1975 volumes in figure 6. With these additional volumes, only treatments 1 and 2 have less total board-foot volume than the control plots.

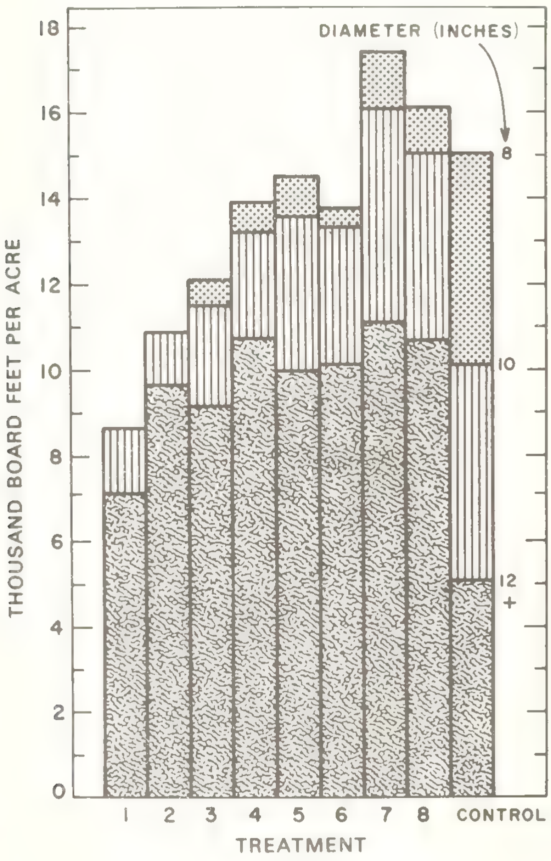


Figure 6.--Cumulative 1975 Scribner board-foot volumes for trees larger than 11.5-, 9.5-, and 7.5-inch d.b.h. to a 6-inch-top diameter by treatments.

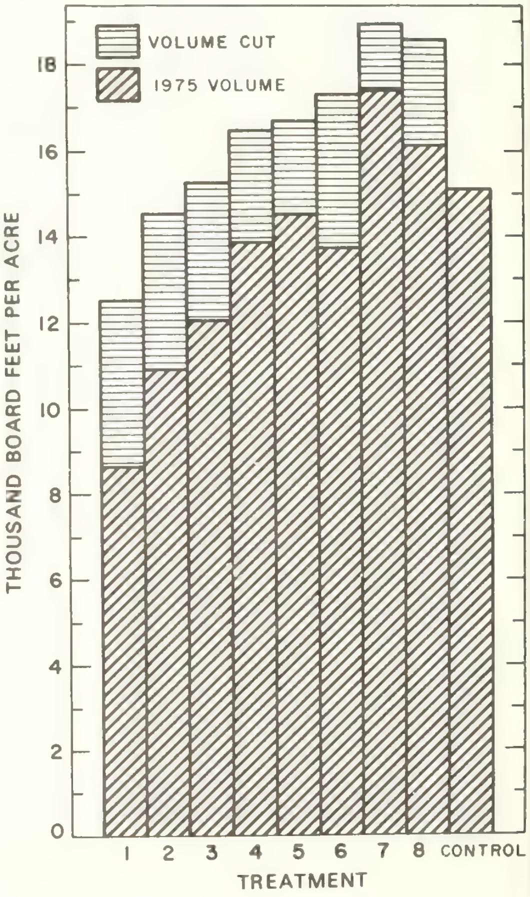


Figure 7.--Scribner board-foot volumes in 1975 and total volumes thinned in 1966, 1970, and 1973 by treatments for trees 7.6-inch d.b.h. and larger to a 6-inch-top diameter, based on 16-foot logs.

Crop Trees

The stand data by treatment for the crop trees are given in table 3. At the end of the third treatment period, the cubic-foot volume of the crop trees in the treatment plots was 1.7 to 2.1 times that of the trees in the control plots. The gross PAI data for crop trees are shown in table 5. The basal area PAI of the crop trees for the third treatment period for the thinned plots was 2.7 to 4.6 times greater than the basal area PAI of the crop trees on the control plots. The basic data for the crop trees by treatment and plot for the third treatment are found in table 8. The gross cubic-foot PAI for the crop trees in the thinned plots are from 2.2 to 3.6 times that of crop trees in the control plots. These data show that the growth rates of the crop trees in the thinned plots are increasing with time relative to those of the crop trees in the control plots (see discussion under "Crop Trees" for the second treatment period).

Discussion, All Treatment Periods, 1963-75

Data for All Live Trees

Natural suppression mortality reduced the number of trees on the control plots by 46 percent (1,727 to 938 per acre). Mortality on the thinned plots was minimal (table 6). After the calibration thinning in 1963, the number of trees per acre in the thinned plots varied from 328 to 365. As a result of three treatment thinnings, the number of trees per acre in 1975 varied from 83 to 260 (table 2). The average d.b.h. for all trees on the thinned plots at the end of the 1963 growing season was just over 5.0 inches. By the end of the 1975 growing season, the average d.b.h. of trees on the thinned plots varied from 10.9 to 13.2 inches. In contrast, the average d.b.h. of trees on the control plots was 3.8 inches in 1963 and 7.1 inches in 1975.

Basal area per acre for the thinned plots varied only from 49.0 to 50.4 square feet at the beginning of the calibration period (1963). By the end of the 1975 growing season, the basal area per acre for the thinned plots ranged from 77.0 to 169.8 square feet because of treatment differences. The basal area per acre of the control plots increased from 138.1 square feet in 1963 to 261.0 square feet in 1975. The cubic-foot volume per acre for the thinned plots varied from 720 to 768 in 1963 and from 2,192 to 4,959 in 1975. The control plots contained 1,982 cubic feet per acre in 1963 and 7,508 in 1975 (table 2).

Table 12 presents net PAI per acre for the average diameter, basal area, and cubic volumes for all trees. The basal area PAI for the thinned plots during the calibration period varied from 11.8 to 12.7 square feet; for the control plots, it was 15.5 square feet. For the first treatment period, the basal area PAI varied from 11.1 to 13.6 square feet, and the control plots averaged 11.0 square feet. For the second treatment period, the basal area PAI varied from 8.2 to 12.4 square feet for the thinned plots and averaged 9.2 square feet for the control plots. For the third treatment period, the basal area PAI of the thinned plots varied from 6.3 to 9.9 square feet, and that of the control plots averaged 2.3 square feet. From 1963 through 1975, treatments 5, 6, 7, and 8 each had a larger basal area increment than the control plot (table 12). Table 4 shows that the basal area PAI for all plots was considerably lower for the 1972 growing season which accounts for some of the difference between the PAI for the first treatment period and the second treatment period for treatment 7.

A comparison of the change in cubic-foot PAI for the treatments and for the control plots shows that the change in cubic-foot PAI for treaments 3 through 8 was greater than that for the control plots for both the first and second treatment periods. For example, PAI for treatment 7 was 275, 428, and 496 for the calibration, first treatment, and second treatment periods, respectively; the corresponding PAI for the control plots was 460, 512, and 515 (table 12). Thus, treatment 7 PAI increased 153 cubic feet between the calibration period and the first treatment period and 68 cubic feet between the first treatment period and the second treatment period, compared with 52 and 3 cubic feet for the control plots.

For the third treatment period, the cubic-foot PAI for treatments 1 and 2 was less than the cubic-foot PAI for treatments 1 and 2 for all previous periods (table 12). The cubic-foot PAI for all treatments for the third treatment period was below that for the second treatment period. Only treatment 1, the lowest level of growing stock, had a lower PAI than the control plots. The large reduction in the PAI for the control plots is attributed to the mortality that occured in 1974. A comparison of the PAI between treatments 1 and 2 and between treatments 3 and 4 for the second and third treatment periods shows that the increased level of growing stock in treatments 2 and 4 has produced an increased PAI. A comparison of the PAI between treatments 5 and 6 and between treatments 7 and 8 for the second and third treatment periods shows that the decreased level of growing stock in treatments 6 and 8 has produced a decreased PAI.

There was no ingrowth in any of the plots from 1964 through 1975.

Data for All Live and Dead (Mortality) Trees

The cumulative gross basal area yield for all trees by treatment and thinning period is shown in figure 8. The amount of material removed by the calibration thinning was derived from the control plot data since records were not kept of the actual amount removed during the calibration thinning.

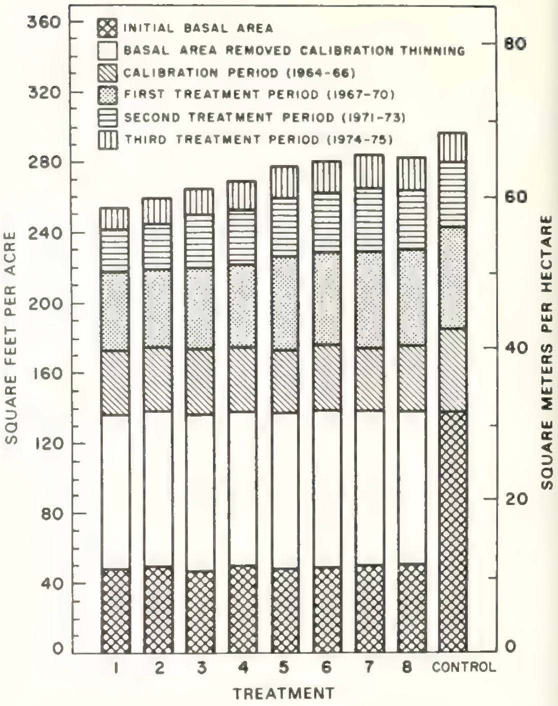


Figure 8.--Cumulative gross basal area yield by treatment and thinning period.

Figure 9 shows the gross cubic-foot yield by treatment and thinning period. Note the uniformity of initial volume even though the initial level of growing stock was determined by basal area. There were only minor fluctuations in cubic-foot volume increment during the calibration period. Growth during the first and second treatment periods is directly correlated with the level of growing stock in each treatment period (tables 2 and 4). In the third treatment period, however, treatment 7 with a beginning volume of 4,092 cubic feet had a cubic-foot PAI of 437 compared with a beginning volume of 6,955 cubic feet and a cubic-foot PAI of 440 for the control plots. Treatment 7 had the greatest total cubic-foot yield of any treatment. Figures 10 and 11 show the gross periodic annual increment by treatment and thinning period. Figure 10 illustrates the relationship of the gross PAI by period within each treatment. Treatments 5, 6, 7, and 8 each had a greater difference in gross cubic-foot PAI between the calibration period and the first treatment period than did the control plots. This was also true between the first treatment period and the second treatment period. For example the gross PAI for treatment 7 was 275 cubic feet for the calibration period and 428 cubic feet for the first treat-

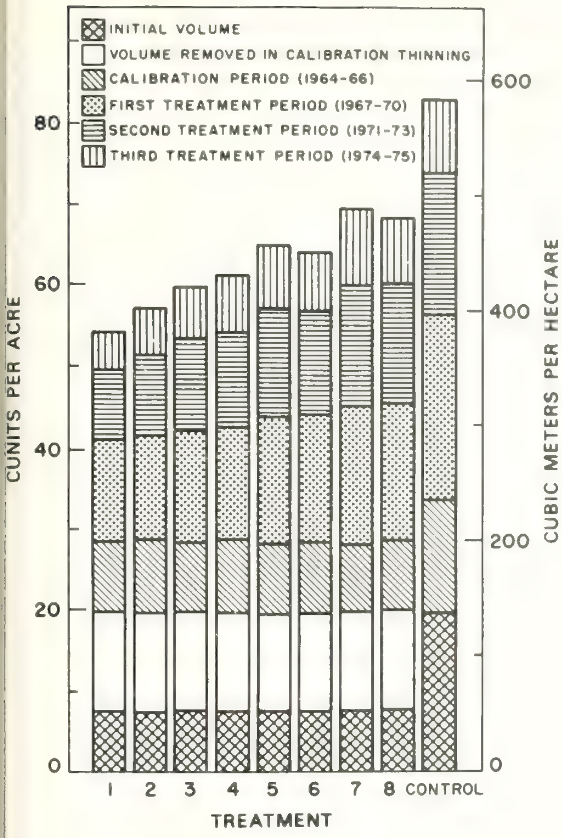


Figure 9.--Gross cubic-foot yield by treatment and thinning period; a cunit is 100 cubic feet.

ment period, a difference of 153 cubic feet. The gross PAI difference for the control plots between the calibration period and the first treatment period was 104 cubic feet. The difference between the first treatment period and the second treatment period in gross PAI for treatment 7 was 63 cubic feet compared with 10 cubic feet for the control plots. For the third treatment period, the gross cubic-foot PAI increment for each treatment and for the control was less than it had been during the second treatment period.

Although the gross basal area PAI decreased for each treatment period for the control plots (16.2, 14.2, 12.3, and 8.8 for the calibration through third treatment periods), the gross cubic-foot PAI increased for the control plots for each period except the third treatment period (469, 573, 583, and 440 for the calibration through third treatment periods)(table 4).

Figure 11 illustrates the relationship of the gross PAI by treatment within each period. Significant changes have occurred in the comparative growth rates of the control and the treatments.

The treatments during the calibration period had similar rates of growth because they had nearly equal levels of growing stock; however, growth was much lower than that for the controls because the levels of growing stock in the treatments were severely reduced.

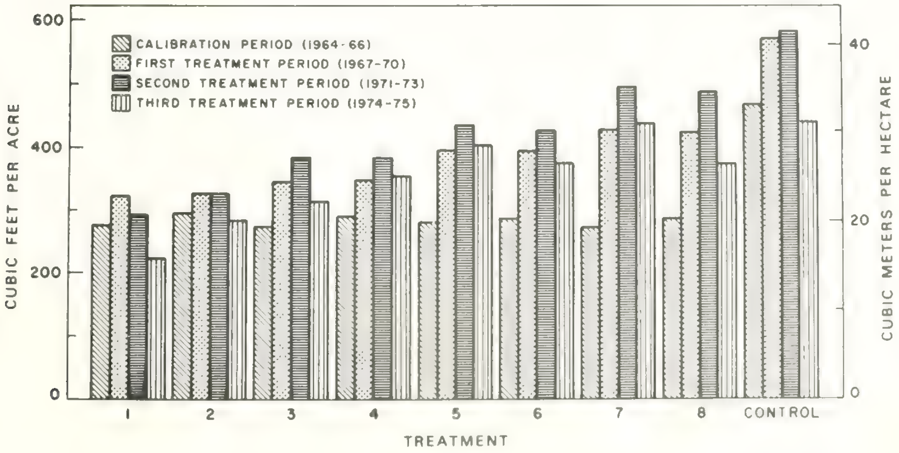


Figure 10.--Gross periodic annual increment by treatment and thinning period.

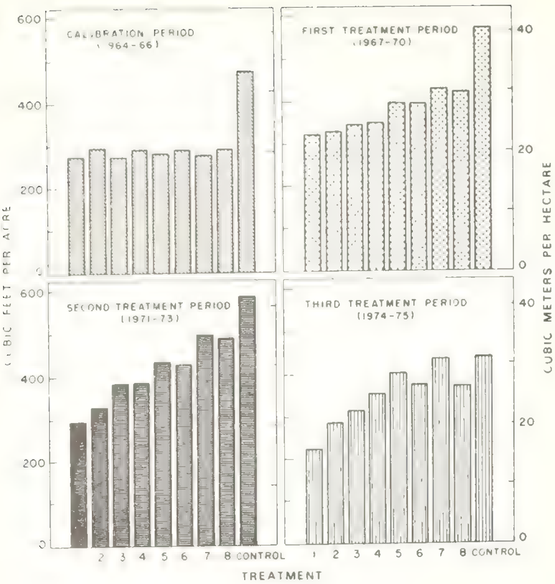


Figure 11.--Gross periodic annual increment by treatment for each treatment period.

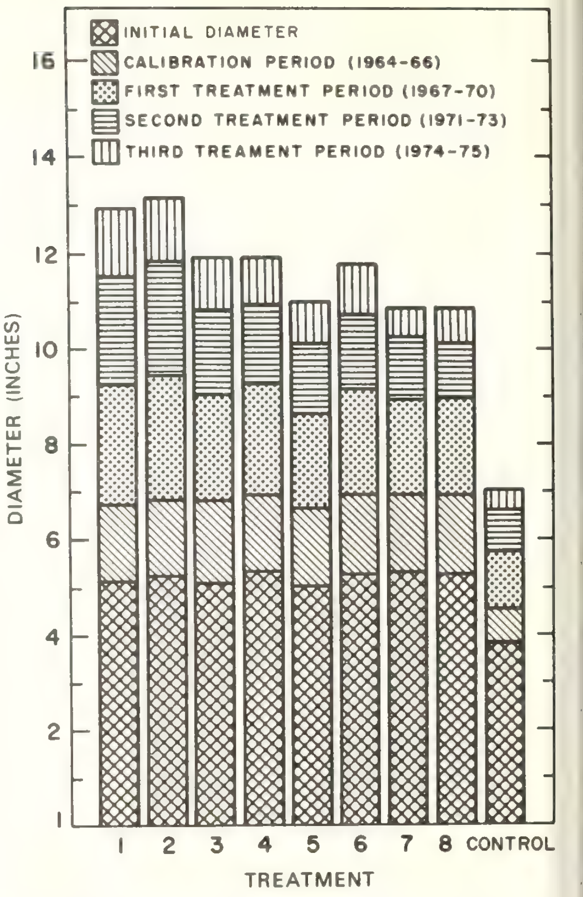


Figure 12.--Quadratic mean diameter growth by treatment and thinning period.

During the first and second treatment periods, growth increased with the level of growing stock. In the first treatment period, there were, in effect, only four treatments, since treatments 1 and 2 were the same, as were 3 and 4, 5 and 6, and 7 and 8. Thus, the PAI was uniform within each pair of treatments but increased with an increased level of growing stock. The PAI differential among treatments continued to be more marked during the second treatment period. For the third treatment period, figure 11 shows the effect of increasing the level of growing stock for treatments 2 and 4 and decreasing the level of growing stock for treatments 6 and 8. It also shows that the difference in growth was much less between treatments 5 and 7 and the control.

The differences in PAI between treatments 3, 4, 5, 6, 7, and 8 and the control became smaller with each succeeding treatment period. In contrast, treatment 1 shows a larger difference in PAI compared with the control. Treatment 2 did show a slightly smaller difference in PAI compared with the control during the third treatment period. Treatment 7 had the largest gross cubic-foot PAI of all the treatments for each treatment period.

Figure 12 gives the quadratic mean diameter growth by treatment and thinni period. Treatments 1 and 2 had the largest quadratic mean diameters, and the control plots the lowest.

At this point, the study dramaticall demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that trees in at leas some of the treatments have the potential to equal or surpass the gross cubic-foot volume of trees in the controls during the next treatment periods

Appendix 1

DESCRIPTION OF EXPERIMENT (as excerpted from Report No. 1)

The experiment is designed to test a number of thinning regimes beginning in young stands made alike at the start through a "calibration" thinning. Thereafter, through the time required for 60 feet of height growth, growing stock is controlled by allowing a specified addition to the growing stock between successive thinnings. Any extra growth is cut and is one of the measured effects of the thinning regime.

EXPERIMENTAL DESIGN

A single experiment consists of eight thinning regimes plus unthinned plots whose growth is the basis for treatment in these regimes. There are three plots per treatment, arranged in a completely randomized design for a total of twenty-seven 1/5-acre plots.

Interaction of site quality and treatment can be evaluated by replicating installations on each site quality class. Cooperative effort has made this replication possible.

CROP TREE SELECTION

Well-formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees before initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees nor more than five--another criterion for stand uniformity.

INITIAL OR "CALIBRATION" THINNING

All 24 treated plots are thinned initially to the same density to minimize the effect of variations in original density on stand growth. Density of residual trees is controlled by quadratic mean diameter (diameter of tree of average basal area) of the residual stand according to the formula:

$$\text{Average spacing in feet} = 0.6167\ (\text{quadratic mean d.b.h}) + 8.$$

If one concentrates on leaving a certain amount of basal area corresponding to an estimated overall quadratic mean d.b.h. ($\bar{D}q$), then the residual number of trees may vary freely and the actual $\bar{D}q$'s may vary ± 10 percent between plots. Alternatively, if emphasis is on leaving a certain number of trees corresponding to an estimated overall $\bar{D}q$, then the basal area may vary and the actual $\bar{D}q$'s may vary ± 15 percent between plots.

TREATMENTS

The eight thinning regimes differ in the amount of basal area allowed to accumulate in the growing stock. The amount of growth retained at any thinning is a predetermined percentage of the gross increase found in the unthinned plots since the last thinning (see the table on the inside front cover). The average residual basal area for all thinned plots after the calibration thinning is the foundation upon which all future growing stock accumulation is based. As used in the study, the three control plots may be thought of as providing a "local gross yield table" for the study area.

For example, the following procedure was used to determine the level of growing stock for each treatment for the beginning of the third treatment period. The average gross square-foot basal area increment per acre of the control plots equals net basal area increment plus mortality.

Net basal area increment per acre	27.67
Basal area of mortality per acre	9.32
Gross basal area increment per acre	36.99

The calculated basal area level in square feet per acre by treatment at the beginning of the third treatment period is:

Treatment No.	Percent basal area to be retained[1]	Basal area at beginning of second treatment period	+	Gross basal area increment	=	Basal area at beginning of third treatment period
1	10	60.4		[2]3.70		[2]64.1
2	30	66.2		11.10		77.3
3	30	81.6		11.10		92.7
4	50	87.0		18.50		105.5
5	50	103.6		18.50		122.1
6	30	97.8		11.10		108.9
7	70	124.5		25.89		150.3
8	50	118.7		18.50		137.2

CONTROL OF THINNING INTERVAL

Thinnings will be made after the calibration thinning whenever average height growth of crop trees comes closest to each multiple of 10 feet.

CONTROL OF TYPE OF THINNING

As far as possible, type of thinning is eliminated as a variable in the treatment thinnings through several specifications:

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).
2. The quadratic mean diameter of cut trees should approximate that of trees available for cutting.
3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

---

[1] See the treatment schedule on the inside front cover.

[2] Example calculation:
10 percent of 36.99 = 3.70; 60.4 + 3.70 = 64.1.

Appendix 2

CALCULATING CUMULATIVE YIELD, TABLES 4 AND 5[1]

Example: treatment 1

	Cubic feet[2]
Volume at end of 1963 growing season, table 2	744
Net increment, 1964-66 (1,579-744 cubic feet), table 2	835
Mortality, 1964-66, table 6 (3 x 0.6)	2
	1,581
Net increment, 1966-70 (2,314-1,027 cubic feet), table 2	1,287
Mortality, 1966-70	0
1,581 + 1,287 =	2,868
Net increment, 1970-73 (2,303-1,423 cubic feet), table 2	880
Mortality, 1970-73	0
2,868 + 880 =	3,748
Net increment, 1973-75 (2,192-1,745 cubic feet), table 2	447
Mortality, 1973-75	0
3,748 + 447 =	4,195

---

[1] Does not include the material removed during the calibration thinning.

[2] Inside bark.

Table 1--Average height of crop trees by treatment and year

Treatment number	Average height[1] (feet)				
	1963	1966	1970	1973	1975[2]
1	35.9	46.0	58.7	68.5	73.7
2	35.1	46.0	59.5	70.1	76.9
3	36.1	45.8	58.7	69.8	75.7
4	36.8	47.3	60.2	70.2	77.5
5	35.7	46.6	59.6	69.5	75.4
6	36.7	46.0	59.1	68.8	74.8
7	35.9	45.6	59.2	69.4	75.8
8	36.3	46.2	59.7	70.0	75.0
Control	36.5	45.9	58.6	67.0	78.2

[1] Differences in average height between this report and Report No. 2 are due to several changes in crop trees.

[2] Heights of trees 10-inch d.b.h. and larger were used because some of the measured crop trees are now part of the understory.

Table 2--Stand data for all live trees in English units, at beginning and end of periods, by treatment

Number of trees per acre[1]

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	353	352	215	215	118	118	118	118	83	83	83
2	343	342	207	207	125	125	125	123	97	97	97
3	343	342	252	252	175	175	175	175	140	140	140
4	333	330	243	243	180	180	180	180	160	160	160
5	365	363	312	312	250	248	248	248	213	213	212
6	338	338	283	283	210	210	210	210	168	168	168
7	328	328	323	323	287	287	287	287	262	260	260
8	337	335	327	327	275	275	275	275	242	240	240
Control	1,727	1,640	1,640	1,272	1,272	1,203	1,145	1,087	1,087	968	938

Quadratic mean diameter at breast height[5] (inches)

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	5.1	6.7	6.9	9.2	9.7	10.3	10.9	11.5	11.9	12.5	13.0
2	5.2	6.8	7.0	9.4	9.9	10.5	11.1	11.8	12.0	12.6	13.2
3	5.1	6.8	6.8	9.0	9.3	9.8	10.3	10.8	11.0	11.5	11.9
4	5.3	6.9	7.0	9.2	9.4	10.0	10.5	10.9	11.0	11.4	11.9
5	5.0	6.6	6.6	8.6	8.7	9.2	9.6	10.1	10.2	10.6	11.0
6	5.2	6.9	7.0	9.1	9.2	9.8	10.3	10.7	10.9	11.3	11.8
7	5.3	6.9	6.9	8.9	8.9	9.4	9.8	10.2	10.3	10.6	10.9
8	5.2	6.9	6.9	8.8	8.9	9.4	9.8	10.1	10.2	10.6	10.9
Control	3.8	4.5	4.5	5.7	5.7	6.0	6.3	6.6	6.6	7.0	7.1

Basal area per acre (square feet)

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	49.4	85.5	55.1	99.5	60.4	68.9	76.2	85.1	64.4	70.6	77.0
2	50.0	87.1	55.9	100.5	66.2	75.5	84.3	93.3	76.5	83.9	91.4
3	49.0	85.0	64.2	111.5	81.6	91.8	100.9	111.3	92.4	100.8	108.9
4	50.4	86.7	65.6	112.6	87.0	97.2	107.1	117.1	105.5	114.2	123.1
5	49.2	86.0	74.9	126.5	103.6	115.1	125.6	137.6	121.1	131.1	140.1
6	49.9	88.0	75.1	127.4	97.8	109.7	120.3	131.5	108.3	117.8	127.3
7	50.1	85.9	84.9	139.4	124.5	137.6	148.7	161.8	150.0	160.2	169.8
8	50.4	87.8	85.8	139.3	118.7	131.4	142.7	154.3	137.0	146.2	155.6
Control	138.1	184.7	184.7	228.6	228.6	239.2	247.4	256.3	256.3	255.9	261.0

Total stem volume per acre[6] (cubic feet[7])

Treatment numbers	Calibration		1st treatment period		2d treatment period		3d treatment period	
	1963	1966	1966[2]	1970	1970[3]	1973	1973[4]	1975
1	744	1,579	1,027	2,314	1,423	2,303	1,745	2,192
2	729	1,614	1,043	2,353	1,568	2,551	2,106	2,677
3	746	1,578	1,197	2,592	1,901	3,058	2,543	3,174
4	749	1,623	1,237	2,662	2,066	3,218	2,903	3,617
5	720	1,565	1,371	2,961	2,432	3,736	3,291	4,091
6	743	1,599	1,370	2,952	2,274	3,555	2,933	3,685
7	750	1,574	1,555	3,268	2,920	4,409	4,092	4,959
8	768	1,634	1,598	3,291	2,807	4,261	3,789	4,540
Control	1,982	3,362	3,362	5,411	5,411	6,955	6,955	7,508

[1] Rounded to nearest whole tree.

[2] 1966 data minus thinned trees.

[3] 1970 data minus thinned trees.

[4] 1973 data minus thinned trees.

[5] Diameter of tree of mean basal area.

[6] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[7] Inside bark.

Table 2A--Stand data for all live trees in metric units, at beginning and end of periods, by treatment

Number of trees per hectare[1]

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	873	869	531	531	292	292	292	292	206	206	206
2	848	844	511	511	309	309	309	305	239	239	239
3	848	844	622	622	432	432	432	432	346	346	346
4	824	815	601	601	445	445	445	445	395	395	395
5	902	898	770	770	618	614	614	614	527	527	523
6	836	836	700	700	519	519	519	519	416	416	416
7	811	811	799	799	708	708	708	708	647	642	642
8	832	828	807	807	680	680	680	680	597	593	593
Control	4,267	4,053	4,053	3,142	3,142	2,973	2,829	2,685	2,685	2,392	2,318

Quadratic mean diameter at breast height[5] (centimeters)

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	12.9	17.0	17.4	23.4	24.6	26.2	27.7	29.2	30.2	31.7	33.1
2	13.1	17.4	17.9	24.0	25.0	26.7	28.2	29.8	30.6	32.0	33.5
3	13.0	17.1	14.7	22.9	23.5	24.9	26.2	27.4	27.9	29.2	30.3
4	13.4	17.6	17.9	23.4	23.9	25.4	26.7	27.7	27.9	28.9	30.2
5	12.6	16.7	16.9	21.9	22.1	23.4	24.4	25.6	25.9	26.9	28.0
6	13.2	17.5	17.7	23.1	23.5	24.9	26.2	27.2	27.6	28.7	29.9
7	13.4	17.6	17.6	22.6	22.7	23.9	24.9	25.8	26.0	26.9	27.8
8	13.3	17.6	17.6	22.5	22.6	23.9	24.9	25.8	25.9	26.9	27.7
Control	9.7	11.5	11.5	14.6	14.6	15.2	16.0	16.7	16.7	17.8	18.1

Basal area per hectare (square meters)

Treatment numbers	Calibration		1st treatment period		2d treatment period				3d treatment period		
	1963	1966	1966[2]	1970	1970[3]	1971	1972	1973	1973[4]	1974	1975
1	11.3	19.6	12.7	22.8	13.9	15.8	17.5	19.5	14.8	16.2	17.7
2	11.5	20.0	12.8	23.1	15.2	17.3	19.3	21.3	17.6	19.3	21.0
3	11.3	19.5	14.7	25.6	18.7	21.1	23.2	25.5	21.2	23.1	25.0
4	11.6	19.9	15.1	25.9	20.0	22.3	24.6	26.9	24.2	26.2	28.3
5	11.3	19.7	17.2	29.0	23.8	26.4	28.8	31.6	27.8	30.1	32.2
6	11.4	20.2	17.2	29.2	22.5	25.2	27.6	30.2	24.9	27.0	29.2
7	11.5	19.7	19.5	32.0	28.6	31.6	34.1	37.1	34.4	36.8	39.0
8	11.6	20.2	19.7	32.0	27.2	30.2	32.7	35.4	31.4	33.6	35.7
Control	31.7	42.4	42.4	52.5	52.5	54.9	56.8	58.8	58.8	58.7	59.9

Total stem volume per hectare[6] (cubic meters[7])

Treatment numbers	Calibration		1st treatment period		2d treatment period		3d treatment period	
	1963	1966	1966[2]	1970	1970[3]	1973	1973[4]	1975
1	52	111	72	162	100	161	122	153
2	51	113	73	165	110	178	147	187
3	52	110	84	181	133	214	178	222
4	52	114	87	186	145	225	203	253
5	50	110	96	207	170	261	230	286
6	52	112	96	207	159	249	205	258
7	52	110	109	229	204	308	286	347
8	54	114	112	230	196	298	265	318
Control	139	235	235	379	379	487	487	525

---

[1] Rounded to nearest whole tree.

[2] 1966 data minus thinned trees.

[3] 1970 data minus thinned trees.

[4] 1973 data minus thinned trees.

[5] Diameter of tree of mean basal area.

[6] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[7] Inside bark.

Table 3--Stand data for crop trees at beginning and end of treatment periods, by treatment

Treatment number	Number of trees per acre[1]				Quadratic mean diameter at breast height[2] (inches)							
	1963-70	1973	1974	1975	1963	1966	1970	1971	1972	1973[2]	1974	1975
1	80	80	80	80	5.7	7.5	10.1	10.8	11.3	12.0	12.6	13.1
2	80	78	78	78	5.9	7.8	10.4	11.1	11.8	12.4	13.0	12.6
3	80	80	80	80	5.8	7.6	10.0	10.6	11.1	11.6	12.2	12.6
4	80	80	80	80	5.9	7.8	10.2	10.8	11.3	11.9	12.3	12.8
5	80	80	80	80	5.8	7.7	10.0	10.6	11.0	11.6	12.1	12.5
6	80	80	80	80	5.9	7.8	10.1	10.7	11.1	11.7	12.2	12.7
7	80	80	80	80	6.1	7.9	10.1	10.6	11.0	11.5	11.9	12.2
8	80	80	80	80	5.8	7.7	9.8	10.4	10.8	11.2	11.6	12.0
Control	80	80	80	80	5.6	6.7	8.0	8.3	8.5	8.8	9.0	9.2

Treatment number	Basal area per acre (square feet)								Total stem volume per acre[3] (cubic feet[4])				
	1963	1966	1970	1971	1972	1973	1974	1975	1963	1966	1970	1973	1975
1	14.4	24.7	44.4	50.7	56.1	62.6	68.7	74.9	226	470	1,056	1,698	2,133
2	15.0	26.3	47.3	54.1	60.5	65.2	71.6	69.0	226	504	1,139	1,808	2,301
3	14.6	25.3	43.6	49.0	53.8	59.3	64.6	69.6	225	475	1,025	1,641	2,043
4	15.3	26.3	45.4	50.6	56.0	61.3	66.3	71.7	236	512	1,098	1,707	2,133
5	14.6	25.7	43.5	48.6	53.2	58.4	63.5	68.2	227	493	1,045	1,613	2,016
6	15.0	26.2	44.5	49.7	54.5	59.5	64.6	70.1	233	491	1,054	1,633	2,046
7	16.1	27.0	44.2	48.9	52.8	57.4	61.4	65.1	246	509	1,058	1,594	1,921
8	14.5	25.8	42.1	46.8	50.8	54.7	58.4	62.3	227	491	1,020	1,538	1,847
Control	13.8	19.6	27.7	29.8	31.5	33.5	34.9	36.3	217	385	689	947	1,086

[1] Rounded to nearest whole tree.

[2] Diameter of tree of mean basal area.

[3] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[4] Inside bark.

Table 4--Gross periodic annual growth, total growth, and cumulative volume yield, in English units, for all trees, by treatment period

Quadratic mean diameter increment at breast height

ent rs	Calibration period		1st treatment period		2d treatment period					3d treatment period				Total, 1963-75	
	1963-66		1966-70		1971	1972	1973	1970-73		1974	1975	1973-75			
	Inch	Percent	Inch	Percent	- - - Inch - - -			Inch	Percent	- - Inch - -		Inch	Percent	Inch	Percent
1	0.53	10.5	0.59	8.6	0.66	0.53	0.62	0.60	6.2	0.57	0.55	0.56	4.7	6.9	135
2	.55	10.6	.60	8.5	.67	.53	.59	.62	6.3	.57	.56	.56	4.7	7.0	134
3	.54	10.5	.54	7.9	.56	.49	.51	.52	5.6	.49	.45	.47	4.3	6.2	122
4	.55	10.4	.54	7.7	.54	.54	.48	.50	5.3	.44	.44	.44	4.0	6.2	117
5	.54	10.9	.50	7.5	.49	.41	.45	.45	5.2	.41	.41	.40	3.9	5.8	116
6	.57	11.0	.53	7.6	.54	.46	.47	.49	5.3	.47	.44	.46	4.2	6.2	119
7	.55	10.4	.49	7.1	.46	.38	.42	.42	4.7	.38	.31	.33	3.2	5.6	106
8	.56	10.7	.48	6.9	.47	.44	.39	.42	4.7	.38	.33	.34	3.3	5.6	108
ntrol	.21	5.5	.16	3.5	.17	.14	.15	.15	2.6	.12	.11	.11	1.7	1.9	50

Basal area per acre

	Calibration period		1st treatment period		2d treatment period					3d treatment period				Total, 1963-75	
	1963-66		1966-70		1971	1972	1973	1970-73		1974	1975	1973-75			
	Square feet	Percent	Square feet	Percent	- - Square feet - -			Square feet	Percent	Square feet		Square feet	Percent	Square feet	Percent
1	12.1	24.5	11.1	20.1	8.5	7.3	8.9	8.2	13.6	6.3	6.4	6.3	9.8	117.9	239
2	12.4	24.8	11.2	20.0	9.3	8.3	9.2	9.1	13.7	7.4	7.5	7.5	9.8	124.1	248
3	12.0	24.6	11.8	18.4	10.1	9.2	10.4	9.9	12.1	8.5	8.1	8.3	8.9	129.6	264
4	12.2	24.2	11.7	17.9	10.8	10.0	10.0	10.1	11.6	8.7	8.9	8.8	8.3	131.3	261
5	12.3	25.1	12.9	17.2	11.5	10.5	12.0	11.5	11.1	10.1	9.0	9.8	8.1	142.2	289
6	12.7	25.5	13.1	17.4	11.8	10.6	11.2	11.2	11.5	9.4	9.5	9.5	8.8	143.0	287
7	11.9	23.9	13.6	16.0	13.1	11.2	13.1	12.5	10.0	10.2	9.7	10.0	6.7	147.6	295
8	12.6	24.9	13.4	15.6	12.8	11.3	11.6	11.9	10.0	9.2	9.4	9.4	6.9	145.3	288
ntrol	16.2	11.7	14.2	7.7	14.0	11.1	11.8	12.3	5.4	9.4	8.2	8.8	3.4	159.9	116

Total stem volume per acre[1]

	Periodic annual growth										Cumulative yield[2]			
	Calibration period		1st treatment period		2d treatment period		3d treatment period		Total, 1963-75					
	1963-66		1966-70		1970-73		1973-75				1966	1970	1973	1975
	Cubic feet[3]	Percent	Cubic feet[3]	Percent	Cubic feet[3]	Percent	Cubic feet[3]	Percent	Cubic feet[3]	Percent	- - - Cubic feet[3] - - -			
1	279	37.5	322	31.3	293	20.6	223	12.8	3,451	464	1,581	2,868	3,748	4,195
2	296	40.6	328	31.4	328	20.9	286	13.6	3,754	515	1,616	2,926	3,912	4,484
3	278	37.3	349	29.1	385	20.3	316	12.4	4,017	538	1,581	2,975	4,131	4,762
4	293	39.1	356	28.8	384	18.6	357	12.3	4,171	557	1,628	3,054	4,206	4,920
5	283	39.4	398	29.0	439	18.1	408	12.4	4,573	635	1,570	3,160	4,477	5,293
6	285	38.4	396	28.9	427	18.8	376	12.8	4,472	602	1,599	3,182	4,463	5,215
7	275	36.6	428	27.5	496	17.0	437	10.7	4,900	653	1,574	3,286	4,775	5,650
8	290	37.7	423	26.5	485	17.3	378	10.0	4,772	621	1,637	3,330	4,784	5,540
ntrol	469	23.6	573	17.0	583	10.8	440	6.3	6,328	319	3,388	5,680	7,430	8,310

[1] erived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. Fc. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[2] ee appendix for explanation of how cumulative yield was derived. The cumulative volume yield data do not include the volume during the calibration thinning (estimated to be 1,238 ft^3).

[3] nside bark.

Table 4A--Gross periodic annual growth, total growth, and cumulative volume yield, in metric units, for all trees, by treatment period

Treatment numbers	Quadratic mean diameter increment at breast height													
	Calibration period		1st treatment period		2d treatment period					3d treatment period				Total, 19
	1963-66		1966-70		1971	1972	1973	1970-73		1974	1975	1973-75		
	Centimeter	Percent	Centimeter	Percent	- - Centimeter - -			Centimeter	Percent	Centimeter		Centimeter	Percent	Centimeter
1	1.3	10.5	1.5	8.6	1.68	1.35	1.57	1.5	6.2	1.45	1.40	1.4	4.7	17.5
2	1.4	10.6	1.5	8.5	1.70	1.35	1.50	1.5	6.1	1.45	1.42	1.4	4.7	17.8
3	1.4	10.5	1.4	7.9	1.42	1.24	1.30	1.3	5.6	1.24	1.14	1.2	4.3	15.7
4	1.4	10.4	1.4	7.7	1.37	1.37	1.22	1.3	5.3	1.12	1.12	1.1	4.0	15.7
5	1.4	10.9	1.3	7.5	1.24	1.04	1.14	1.1	5.2	1.04	1.04	1.0	3.9	14.7
6	1.4	11.0	1.3	7.6	1.37	1.17	1.19	1.2	5.3	1.19	1.12	1.2	4.2	15.7
7	1.4	10.4	1.2	7.1	1.17	0.97	1.07	1.1	4.7	0.97	0.79	0.8	3.2	14.2
8	1.4	10.7	1.2	6.9	1.19	1.12	0.99	1.1	4.7	0.97	0.84	0.9	3.3	14.2
Control	0.5	5.5	0.4	3.5	0.43	0.36	0.38	0.4	2.6	0.30	0.28	0.3	1.7	4.8

Treatment numbers	Basal area per hectare													
	Calibration period		1st treatment period		2d treatment period					3d treatment period				Total, 19
	1963-66		1966-70		1971	1972	1973	1970-73		1974	1975	1973-75		
	Square meters	Percent	Square meters	Percent	- Square meters -			Square meters	Percent	- Square meters -		Square meters	Percent	Square meters
1	2.8	24.5	2.5	20.1	1.9	1.7	2.0	1.9	13.6	1.4	1.5	1.5	9.8	27.1
2	2.9	24.8	2.6	20.0	2.1	1.9	2.1	2.0	13.4	1.7	1.7	1.7	9.8	28.5
3	2.8	24.6	2.7	18.4	2.3	2.1	2.4	2.3	12.1	1.9	1.9	1.9	8.9	29.8
4	2.8	24.2	2.7	17.9	2.5	2.3	2.3	2.3	11.6	2.0	2.0	2.0	8.3	30.1
5	2.8	25.1	3.0	17.2	2.6	2.4	2.7	2.6	11.1	2.3	2.1	2.3	8.1	32.6
6	2.9	25.5	3.0	17.4	2.7	2.4	2.6	2.6	11.5	2.2	2.2	2.2	8.8	32.8
7	2.7	23.9	3.1	16.0	3.0	2.6	3.0	2.8	10.0	2.3	2.2	2.3	6.7	33.9
8	2.9	24.9	3.1	15.6	2.9	2.6	2.7	2.7	10.0	2.1	2.2	2.2	6.9	33.4
Control	3.7	11.7	3.3	7.7	3.2	2.5	2.7	2.8	5.4	2.2	1.9	2.0	3.4	36.7

Treatment numbers	Total stem volume per hectare[1]												
	Periodic annual growth										Cumulative yield[2]		
	Calibration period		1st treatment period		2d treatment period		3d treatment period		Total, 1963-75				
	1963-66		1966-70		1970-73		1973-75				1966	1970	1973
	Cubic meters[3]	Percent	Cubic meters[3]	Percent	Cubic meters[3]	Percent	Cubic meters[3]	Percent	Cubic meters[3]	Percent	- - - Cubic meters[3] -		
1	19.5	37.5	22.5	31.3	20.5	20.6	15.6	12.8	241.5	464	110.6	200.7	262.3
2	20.7	40.6	22.9	31.4	22.7	20.7	20.0	13.6	262.7	515	113.1	204.8	273.0
3	19.5	37.3	24.4	29.1	27.0	20.3	22.1	12.4	281.1	538	110.6	208.2	289.1
4	20.5	39.1	24.9	28.8	26.9	18.6	25.0	12.3	291.8	557	113.9	213.7	294.3
5	19.8	39.4	27.8	29.0	30.7	18.1	28.6	12.4	320.0	635	109.8	221.1	313.3
6	20.0	38.4	27.7	28.9	29.9	18.8	26.3	12.8	312.9	602	111.9	222.6	312.3
7	19.2	36.6	30.0	27.5	34.6	16.9	30.6	10.7	342.9	653	110.1	230.0	333.7
8	20.3	37.7	29.3	26.5	33.9	17.3	26.4	10.0	333.9	621	114.6	233.0	334.8
Control	32.8	23.6	40.1	17.0	40.8	10.8	30.8	6.3	442.8	319	237.1	397.4	519.9

---

[1] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fi USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[2] See appendix for how cumulative yield was derived. The cumulative volume yield data do not include the volume removed dur the calibration thinning (estimated to be 125.3 m^3).

[3] Inside bark.

Table 5--Gross periodic annual growth and cumulative volume yield for crop trees, by treatment and treatment period

Treatment numbers	Quadratic mean diameter increment at breast height (inch)								
	1963-66	1966-70	1971	1972	1973	1970-73	1974	1975	1973-75
1	0.59	0.64	0.69	0.56	0.64	0.63	0.58	0.55	0.56
2	.63	.66	.72	.60	.65	.67	.60	.57	.58
3	.61	.60	.59	.51	.55	.55	.52	.46	.49
4	.61	.61	.59	.56	.52	.55	.48	.49	.48
5	.63	.58	.58	.49	.52	.53	.50	.43	.47
6	.63	.59	.57	.50	.50	.53	.50	.51	.50
7	.60	.55	.51	.42	.46	.47	.39	.35	.37
8	.64	.54	.53	.43	.44	.47	.38	.37	.37
Control	.36	.31	.30	.23	.25	.26	.18	.18	.18

	Basal area per acre (square feet)								
	1963-66	1966-70	1971	1972	1973	1970-73	1974	1975	1973-75
1	3.4	4.9	6.3	5.4	6.5	6.1	6.2	6.2	6.2
2	3.8	5.2	6.8	5.5	6.8	6.7	6.4	6.4	6.4
3	3.5	4.6	5.3	4.8	5.5	5.2	5.3	5.1	5.2
4	3.7	4.8	5.0	5.4	5.3	5.3	5.0	5.3	5.2
5	3.7	4.4	5.5	4.6	5.2	5.0	5.1	4.7	4.9
6	3.8	4.6	5.2	4.8	5.0	5.0	5.2	5.5	5.3
7	3.7	4.3	4.6	4.0	4.6	4.4	4.0	3.7	3.8
8	3.7	4.1	4.7	4.0	4.3	4.3	3.7	3.9	3.8
Control	2.0	2.1	2.1	1.7	2.0	1.9	1.4	1.4	1.4

	Total stem volume per acre[1] (cubic feet[2])							
	Periodic annual growth				Cumulative yield			
	1963-66	1966-70	1970-73	1973-75	1963-66	1966-70	1970-73	1973-75
1	82	146	214	217	470	1,056	1,698	2,133
2	93	159	241	246	504	1,139	1,862	2,301
3	83	137	205	201	475	1,025	1,641	2,043
4	92	146	203	213	512	1,098	1,707	2,133
5	89	138	190	202	493	1,045	1,613	2,017
6	86	141	193	206	491	1,054	1,633	2,046
7	88	137	179	164	509	1,058	1,594	1,921
8	88	132	177	154	491	1,020	1,550	1,847
Control	56	76	86	69	385	689	947	1,086

[1] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[2] Inside bark.

Table 6--Periodic annual mortality of all trees, by treatment and treatment period

Treatment numbers	Number of trees per acre[1]								
	1963-66	1966-70	1971	1972	1973	1970-73	1974	1975	1973-75
1	1	0	0	0	0	0	0	0	0
2	1	0	0	0	2	1	0	0	0
3	1	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0
5	1	0	2	0	0	1	0	1	1
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	2	0	1
8	1	0	0	0	0	0	2	0	1
Control	29	92	69	58	58	62	118	30	74
	Quadratic mean diameter at breast height[2] (inches)								
	1963-66	1966-70	1971	1972	1973	1970-73	1974	1975	1973-75
1	3.5	0	0	0	0	0	0	0	0
2	4.2	0	0	0	4.3	4.3	0	0	0
3	4.1	0	0	0	0	0	0	0	0
4	4.1	0	0	0	0	0	0	0	0
5	5.4	0	7.6	0	0	7.6	0	8.0	8.0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	5.2	0	5.2
8	5.0	0	0	0	0	0	5.0	0	5.0
Control	2.1	2.5	3.1	3.0	3.1	3.0	3.9	4.4	4.0
	Basal area per acre (square feet)								
	1963-66	1966-70	1971	1972	1973	1970-73	1974	1975	1973-75
1	0.04	0	0	0	0	0	0	0	0
2	.05	0	0	0	.17	.06	0	0	0
3	.05	0	0	0	0	0	0	0	0
4	.10	0	0	0	0	0	0	0	0
5	.09	0	.52	0	0	.17	0	.58	.29
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	.25	0	.12
8	.08	0	0	0	0	0	.23	0	.11
Control	.68	3.18	3.46	2.86	3.00	3.10	9.81	3.11	6.46

Treatment numbers	Total stem volume[3] per acre (cubic feet[4])			
	1963-66	1966-70	1970-73	1973-75
1	0.6	0	0	0
2	.8	0	1	0
3	.9	0	0	0
4	1.6	0	0	0
5	1.4	0	4.6	8.3
6	0	0	0	0
7	0	0	0	3.2
8	1.2	0	0	2.6
Control	8.8	60.6	68.8	163.6

[1] Rounded to nearest whole tree.

[2] Diameter of tree of mean basal area.

[3] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[4] Inside bark.

Table 7--Basic data by treatment and plot for all live trees 1971-75 (second and third treatment periods)

Treatment and plot numbers	Number of trees per acre[1]					Quadratic mean diameter at breast height[3] (inches)					Basal area per acre (square feet)					Total stem volume per acre[4] (cubic feet[5])	
	1971	1972	1973[2]	1974	1975	1971	1972	1973[2]	1974	1975	1971	1972	1973[2]	1974	1975	1973[2]	1975
1:																	
3	115	115	115	85	85	10.5	11.1	11.7	12.4	12.9	69.4	76.7	86.0	71.2	77.7	2,246	2,138
8	120	120	120	80	80	10.2	10.7	11.3	12.7	13.2	68.2	75.4	84.2	70.6	76.7	2,361	2,224
20	120	120	120	85	85	10.3	10.8	11.4	12.3	12.9	69.1	76.5	85.1	70.2	76.6	2,301	2,213
2:																	
4	135	135	135	105	105	10.2	10.7	11.3	12.2	12.7	76.0	85.0	93.5	85.2	93.0	2,523	2,626
15	100	100	100	75	75	11.7	12.4	13.1	14.4	15.0	75.3	84.2	93.1	84.5	92.3	2,639	2,810
17	140	140	135	110	110	9.9	10.5	11.3	11.7	12.2	75.3	83.6	93.3	81.9	89.0	2,489	2,596
3:																	
7	200	200	200	160	160	9.2	9.6	10.1	10.8	11.2	91.8	101.3	117.5	101.0	109.2	3,096	3,158
11	160	160	160	125	125	10.3	10.8	11.3	12.2	12.7	92.1	101.0	111.5	101.4	109.7	3,080	3,187
21	165	165	165	135	135	10.1	10.6	11.0	11.7	12.1	91.4	100.6	109.9	100.1	107.7	2,998	3,177
4:																	
5	205	205	205	180	180	9.3	9.8	10.3	10.8	11.2	96.7	107.1	117.8	115.0	124.1	3,017	3,333
18	185	185	185	165	165	9.9	10.3	10.8	11.3	11.7	98.1	107.8	118.0	114.3	122.9	3,241	3,661
23	150	150	150	135	135	10.9	11.4	11.9	12.4	12.9	96.6	106.4	115.2	113.4	122.3	3,398	3,857
5:																	
9	250	250	250	215	215	9.2	9.6	10.0	10.6	10.9	114.6	125.2	136.9	130.7	139.2	3,883	4,262
24	230	230	230	200	200	9.6	10.0	10.4	11.0	11.4	114.9	125.0	137.1	131.3	140.7	3,677	3,975
27	265	265	265	224	220	8.9	9.4	9.8	10.3	10.8	115.7	126.6	138.8	131.3	140.6	3,647	4,035
6:																	
1	210	210	210	170	170	9.8	10.4	10.7	11.2	11.7	109.7	120.5	131.1	116.9	126.4	3,543	3,681
2	225	225	225	180	180	9.4	9.9	10.4	11.0	11.4	109.7	120.4	132.0	117.7	127.6	3,449	3,556
25	195	195	195	155	155	10.1	10.6	11.1	11.8	12.3	109.6	119.9	131.6	118.7	127.8	3,672	3,818
7:																	
12	300	300	300	275	275	9.1	9.5	9.9	10.3	10.6	137.0	148.0	161.0	160.1	169.4	4,402	4,996
14	270	270	270	245	245	9.4	9.8	10.2	10.9	11.3	138.5	149.7	163.5	160.0	169.4	4,477	4,930
19	290	290	290	260	260	9.3	9.7	10.1	10.6	11.0	137.2	148.6	161.0	160.4	170.7	4,348	4,952
8:																	
6	300	300	300	260	260	9.0	9.4	9.7	10.1	10.4	131.8	143.2	154.4	145.9	154.9	4,184	4,462
13	270	270	270	240	235	9.4	9.8	10.2	10.6	11.0	130.6	140.9	153.0	144.9	153.9	4,103	4,346
16	255	255	255	225	225	9.7	10.2	10.6	11.0	11.3	131.9	144.0	155.4	147.7	157.9	4,496	4,812
Control:																	
10	1,355	1,270	1,205	1,205	1,100	5.6	5.8	6.1	6.3	6.5	228.7	234.9	243.5	246.2	250.0	6,264	6,668
22	1,025	1,005	965	965	800	6.7	7.0	7.2	7.7	8.0	255.0	265.5	275.4	272.8	277.1	7,843	8,530
26	1,230	1,160	1,090	1,090	915	5.9	6.2	6.5	7.0	7.2	233.9	241.9	250.0	248.8	255.9	6,753	7,425

[1] Rounded to nearest whole tree.

[2] Data before thinning.

[3] Diameter of tree of mean basal area.

[4] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[5] Inside bark.

Table 8- Basic data by treatment and plot for crop trees (second and third treatment periods), 1971-75

Treatment and plot numbers	Number of trees per acre[1]			Quadratic mean diameter at breast height[2] (inches)					Basal area per acre (square feet)					Total stem volume per acre[3] (cubic feet[4])		Height (feet)	
	1971	1973	1975	1971	1972	1973	1974	1975	1971	1972	1973	1974	1975	1973	1975	1973	1975
1:																	
3	80	80	80	10.7	11.3	11.9	12.5	13.1	50.4	55.8	62.2	64.5	74.8	1,632	2,060	67.4	71.9
8	80	80	80	10.9	11.5	12.2	12.7	13.2	52.2	57.9	64.5	70.6	76.7	1,809	2,224	69.7	74.7
20	80	80	80	10.6	11.2	11.8	12.4	12.9	49.4	54.6	61.0	67.0	73.2	1,654	2,113	68.2	73.7
2:																	
4	80	80	80	10.6	11.2	11.8	12.4	12.9	49.2	55.1	60.6	67.1	72.9	1,641	2,064	68.6	72.6
15	80	75	75	12.3	13.0	13.7	14.4	15.0	66.3	74.1	81.7	84.5	92.3	2,329	2,810	74.3	80.4
17	80	80	80	10.3	10.9	11.7	12.0	12.6	46.7	52.8	59.7	63.2	69.0	1,616	2,028	68.0	74.3
3:																	
7	80	80	80	10.1	10.7	11.2	11.8	12.2	44.8	49.6	55.2	60.5	65.4	1,537	1,916	70.7	75.4
11	80	80	80	11.2	11.7	12.2	12.8	13.2	54.4	59.4	65.1	71.1	76.7	1,816	2,241	71.3	75.4
21	80	80	80	10.5	11.0	11.5	11.9	12.4	47.7	52.4	57.5	62.2	66.8	1,570	1,972	67.9	73.7
4:																	
5	80	80	80	10.3	10.9	11.4	11.9	12.4	46.8	51.8	57.0	61.8	66.6	1,493	1,830	65.0	68.0
18	80	80	80	10.1	10.6	11.1	11.6	12.1	44.5	49.1	53.8	58.6	63.3	1,478	1,886	69.5	76.3
23	80	80	80	11.8	12.4	12.9	13.4	14.0	60.6	67.2	73.0	78.7	85.1	2,151	2,683	76.0	82.0
5:																	
9	80	80	80	10.3	10.8	11.3	11.8	12.1	46.4	50.8	55.8	60.5	64.4	1,613	1,992	72.2	77.7
24	80	80	80	11.1	11.6	12.1	12.7	13.1	53.4	58.4	64.1	69.9	75.0	1,773	2,182	69.4	74.5
27	80	80	80	10.3	10.8	11.2	11.8	12.2	46.1	50.5	55.2	60.2	65.1	1,454	1,875	65.9	72.3
6:																	
1	80	80	80	10.7	11.2	11.7	12.2	12.7	50.3	55.2	59.9	64.9	70.3	1,653	2,048	69.3	73.9
2	80	80	80	10.2	10.7	11.2	11.7	12.2	45.8	50.3	54.9	59.9	65.3	1,451	1,842	66.0	71.0
25	80	80	80	11.0	11.5	12.1	12.6	13.1	52.9	57.9	63.6	69.2	74.8	1,796	2,248	71.3	76.8
7:																	
12	80	80	80	10.2	10.6	11.1	11.4	11.8	45.6	49.3	53.6	57.0	60.3	1,482	1,796	69.0	74.5
14	80	80	80	11.1	11.6	12.1	12.6	12.9	54.0	58.7	64.0	68.7	72.8	1,791	2,150	70.7	75.3
19	80	80	80	10.4	10.8	11.2	11.6	11.9	47.0	50.6	54.6	58.5	62.1	1,508	1,817	68.8	73.2
8:																	
6	80	80	80	10.6	11.1	11.5	11.9	12.3	49.0	53.4	57.9	61.8	65.8	1,638	1,972	70.5	74.9
13	80	80	80	10.6	11.0	11.5	11.9	12.3	48.8	52.7	57.7	61.6	65.6	1,578	1,884	68.8	73.0
16	80	80	80	9.9	10.3	10.7	10.9	11.2	45.2	49.1	53.1	51.9	55.5	1,525	1,685	70.8	75.2
Control:																	
10	80	80	80	8.0	8.3	8.5	8.7	8.8	28.2	29.8	31.7	32.8	33.8	871	971	65.7	68.7
22	80	80	80	8.5	8.7	8.9	9.1	9.4	30.6	32.0	33.8	35.2	36.9	998	1,156	69.0	76.3
26	80	80	80	8.4	8.7	8.9	9.1	9.3	30.8	32.7	34.8	36.4	37.9	974	1,131	66.0	70.4

[1] Rounded to nearest whole tree.

[2] Diameter of tree of mean basal area.

[3] Derived from equations developed by David Bruce and Donald J. DeMars (1974 Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[4]

Table 9--Stand table after second treatment thinning, 1970

D.b.h. class	Treatment number								
	1	2	3	4	5	6	7	8	Control
Inches	In number of trees per acre[1]								
2									53
3									223
4		2			2				267
5			3	5	15	5	8	18	220
6	5	3	15	10	28	13	32	23	172
7	7	7	22	22	30	17	33	38	125
8	20	20	35	30	47	47	47	50	103
9	30	30	32	32	57	48	67	52	58
10	28	22	28	33	42	30	58	50	30
11	8	23	18	32	17	20	25	22	12
12	17	12	17	10	7	18	10	17	3
13	3	7	3	5	7	2	7	5	3
14			2	2					
15									2
Total	118	125	175	180	250	210	287	275	1,272

[1] Rounded to nearest whole tree.

Table 10--Trees removed at beginning of the second and third treatment periods, 1970 and 1973

Treatment number	Number of trees[1]		Quadratic mean diameter at breast height[2] (inches)		Basal area (square feet)				Volume[3] (cubic feet[4])			
					Total		Per tree		Total		Per tree	
	1970	1973	1970	1973	1970	1973	1970	1973	1970	1973	1970	1973
1	97	35	8.6	10.4	39.1	20.7	0.40	0.59	892	558	9.2	15.9
2	82	26	8.8	10.9	34.3	16.8	.42	.65	785	445	9.6	19.1
3	77	35	8.4	10.0	29.9	18.9	.39	.54	690	514	9.0	14.7
4	63	20	8.6	10.3	25.7	11.6	.41	.58	596	316	9.5	15.8
5	62	35	8.3	9.3	22.9	16.5	.37	.47	529	445	8.5	12.7
6	73	42	8.6	10.0	29.5	23.2	.40	.55	678	623	9.3	14.8
7	37	25	8.6	9.3	14.9	11.8	.40	.47	348	317	9.4	12.7
8	52	33	8.6	9.8	20.6	17.3	.40	.52	484	472	9.3	14.3

[1] Rounded to nearest whole tree.

[2] Diameter of tree of mean basal area.

[3] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[4] Inside bark.

Table 11--Stand table at end of second treatment period, 1973

D.b.h. class	Treatment number								
	1	2	3	4	5	6	7	8	Control
Inches	Number of trees per acre[1]								
2									7
3									103
4					2				207
5					5	2	5	8	200
6			7	5	13	5	18	13	153
7	5	2	5	10	30	12	18	22	140
8	3	5	25	22	18	15	32	33	103
9	12	12	15	12	37	33	38	40	72
10	25	17	38	35	38	42	52	40	50
11	13	28	25	33	50	35	58	55	28
12	30	20	25	27	33	28	38	32	13
13	12	20	17	25	10	30	18	20	5
14	15	12	15	7	7	7	7	10	2
15	2	7	2	3	5	2	2	2	2
16	2	2	2	2					2
Total	118	123	175	180	248	210	287	275	1,087

[1] Rounded to nearest whole tree.

Table 12--Periodic annual net increment data for all trees by treatment and thinning period

Treatment numbers	Quadratic mean diameter at breast height[1] (inches)				
	1963-66	1966-70	1970-73	1973-75	1963-75[2]
1	0.53	0.57	0.60	0.55	7.9
2	.53	.60	.63	.60	8.0
3	.57	.55	.50	.45	6.8
4	.53	.55	.50	.45	6.6
5	.53	.50	.47	.40	6.0
6	.57	.52	.50	.45	6.6
7	.53	.50	.43	.30	5.6
8	.57	.47	.40	.35	5.7
Control	.23	.30	.30	.25	3.3
	Basal area per acre (square feet)				
	1963-66	1966-70	1970-73	1973-75	1963-75
1	12.1	11.1	8.2	6.3	121.6
2	12.4	11.1	9.0	7.4	126.8
3	12.0	11.8	9.9	8.2	132.9
4	12.1	11.7	10.0	8.8	133.4
5	12.3	12.9	11.3	9.5	145.0
6	12.7	13.0	11.2	9.5	146.5
7	11.8	13.6	12.4	9.9	152.4
8	12.5	13.4	11.9	9.3	150.3
Control	15.5	11.0	9.2	2.3	136.6
	Volume per acre[3] (cubic feet[4])				
	1963-66	1966-70	1970-73	1973-75	1963-75
1	278	322	293	223	3,225
2	295	327	328	285	3,463
3	277	349	385	315	3,698
4	291	356	384	357	3,423
5	282	398	435	400	4,140
6	285	396	427	376	4,096
7	275	428	496	433	4,559
8	289	423	485	375	4,387
Control	460	512	515	276	5,249

[1] Diameter of tree of mean basal area.

[2] Difference between average diameter at end of 1975 growing season and quadratic mean diameter at end of 1963 growing season.

[3] Derived from equations developed by David Bruce and Donald J. DeMars (1974. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Note PNW-239, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.).

[4] Inside bark.

Table 13--Stand table after third treatment thinning, 1973

D.b.h. class	Treatment number								
	1	2	3	4	5	6	7	8	Control
Inches	In number of trees per acre[1]								
2									7
3									103
4					2				207
5					5	2	5	8	200
6			2	5	10	2	17	10	153
7		2	3	8	20	8	12	22	140
8		0	20	17	17	12	30	27	103
9	7	8	7	8	27	23	35	32	72
10	20	13	35	32	35	33	47	35	50
11	10	20	22	33	48	30	55	53	28
12	20	18	22	23	33	27	35	27	13
13	10	17	15	25	8	27	18	17	5
14	13	10	12	3	3	3	7	10	2
15	2	7	2	3	5	2	2	2	2
16	2	2	2	2					2
Total	83	97	140	160	213	168	262	242	1,087

[1] Rounded to nearest whole tree.

Table 14--Stand table at end of third treatment period, 1975

D.b.h. class	Treatment number								
	1	2	3	4	5	6	7	8	Control
Inches	In number of trees per acre[1]								
3									42
4					2				157
5						2	3	7	163
6				2	12	2	8	7	132
7		2	3	7	12	5	18	18	145
8			15	12	18	7	17	18	83
9		2	7	13	15	10	30	23	95
10	7	10	8	8	28	22	32	32	50
11	17	10	30	32	33	32	48	40	32
12	13	20	23	28	40	33	52	43	22
13	18	15	22	23	32	27	28	30	8
14	12	15	17	22	10	17	17	13	7
15	13	15	12	8	5	12	7	7	2
16		2	2	3	5	2		2	
17	3	7	2	2					2
Total	83	97	140	160	212	168	260	240	938

---

[1] Rounded to nearest whole tree.

Study area	*Cooperator*
Skykomish	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Hoskins	School of Forestry Oregon State University Corvallis, Oregon
Rocky Brook	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Clemons	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Francis	Washington State Department of Natural Resources Olympia, Washington
Iron Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Stampede Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Sayward Forest	Canadian Forestry Service Department of the Environment Victoria, British Columbia
Shawnigan Lake	Canadian Forestry Service Department of the Environment Victoria, British Columbia

Consultative services have been provided by the University of Washington, Seattle, and the Bureau of Land Management, U.S. Department of the Interior.

GPO 988-758

Berg, Alan B., and John F. Bell.
1979. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: Report No. 5--The Hoskins Study, 1963-75. USDA For. Serv. Res. Pap. PNW-257, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Growth data are presented for the first 12 years of management of a young Douglas-fir stand in the Oregon Coast Ranges manipulated to include eight levels of growing stock. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

KEYWORDS: Growing stock (-increment/yield, thinnings, Douglas-fir, *Pseudotsuga menziesii*.

Berg, Alan B., and John F. Bell.
1979. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: Report No. 5--The Hoskins Study, 1963-75. USDA For. Serv. Res. Pap. PNW-257, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Growth data are presented for the first 12 years of management of a young Douglas-fir stand in the Oregon Coast Ranges manipulated to include eight levels of growing stock. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

KEYWORDS: Growing stock (-increment/yield, thinnings, Douglas-fir, *Pseudotsuga menziesii*.

Berg, Alan B., and John F. Bell.
1979. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: Report No. 5--The Hoskins Study, 1963-75. USDA For. Serv. Res. Pap. PNW-257, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Growth data are presented for the first 12 years of management of a young Douglas-fir stand in the Oregon Coast Ranges manipulated to include eight levels of growing stock. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

KEYWORDS: Growing stock (-increment/yield, thinnings, Douglas-fir, *Pseudotsuga menziesii*.

Berg, Alan B., and John F. Bell.
1979. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: Report No. 5--The Hoskins Study, 1963-75. USDA For. Serv. Res. Pap. PNW-257, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Growth data are presented for the first 12 years of management of a young Douglas-fir stand in the Oregon Coast Ranges manipulated to include eight levels of growing stock. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

KEYWORDS: Growing stock (-increment/yield, thinnings, Douglas-fir, *Pseudotsuga menziesii*.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
809 N.E. 6th Ave.
Portland, Oregon 97232

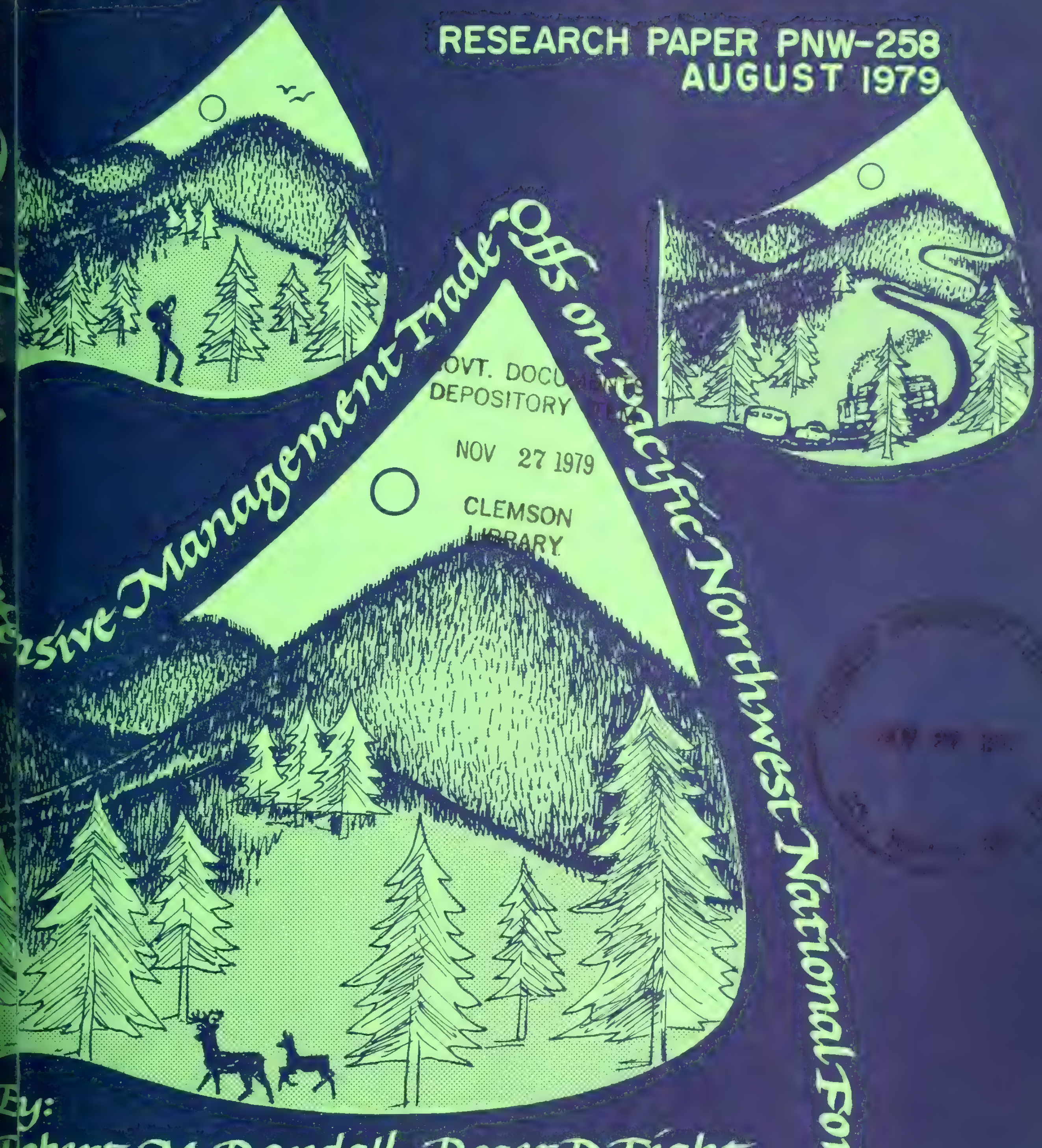
The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

2 . PNW:258

RESEARCH PAPER PNW-258
AUGUST 1979

nsive Management Trade-Offs on Pacific Northwest National Forests



OVT. DOCUMENTS
DEPOSITORY ITEM
NOV 27 1979
CLEMSON
LIBRARY

By:
Robert M. Randall, Roger D. Fight,
Kent R Connaughton,
Robert W. Sassaman, and
K. Norman Johnson

CIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

ACKNOWLEDGMENT

This report is the result of a study requested by John McGuire, Chief, USDA Forest Service. This report presents results for the Pacific Northwest Region of the National Forest System. The data and staff from three National Forests--the Siskiyou, Umatilla, and Willamette National Forests--made this study possible. The principal contributor from the Pacific Northwest Regional Office in Portland, Oregon, was Alfred F. Burkhardt, Jr.

METRIC EQUIVALENTS

1,000 cubic feet = 28.3 cubic meters

1 cubic foot per acre = 0.070 cubic meter per hectare

1 inch = 2.54 centimeters

1 foot = 30.48 centimeters

1 mile = 1.61 kilometers

1 acre = 0.404 hectare

AUTHORS

ROBERT M. RANDALL, ROGER D. FIGHT, KENT P. CONNAUGHTON, and ROBERT W. SASSAMAN are economists, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

K. NORMAN JOHNSON is assistant professor, Department of Forestry and Outdoor Recreation, Utah State University, Logan, Utah.

ROADLESS AREA-INTENSIVE MANAGEMENT TRADE-OFFS ON PACIFIC NORTHWEST NATIONAL FORESTS

REFERENCE ABSTRACT

Randall, Robert M., Roger D. Fight, Kent P. Connaughton,
Robert W. Sassaman, and K. Norman Johnson.
1979. Roadless area-intensive management trade-offs
on Pacific Northwest National Forests. USDA
For. Serv. Res. Pap. PNW-258, 69 p., illus.
Pacific Northwest Forest and Range Experiment
Station, Portland, Oregon.

This study tested the hypothesis that timber harvest levels could be maintained on selected Pacific Northwest National Forests without harvesting from roadless areas, if resources saved by not developing the roadless areas were used for more intensive timber management on the remaining land. The study also examined the employment, financial, environmental, and multiple use implications if such a course of action were followed.

KEYWORDS: Wilderness management, land use, policy (forest), intensive management, economic evaluation.

RESEARCH SUMMARY
RESEARCH PAPER PNW-258
1979

Building roads to provide access to National Forest roadless areas for timber harvest and other multiple use objectives involves a substantial capital investment. It has been suggested that it might be possible to produce as much or more timber from a National Forest by reallocating that investment to timber management practices, such as reforestation, release, and thinning in the areas outside the roadless areas; this would leave roadless areas undeveloped and unmanaged.

The primary objective of this study was to test the hypothesis that as much timber could be harvested from a National Forest without harvesting from its roadless area as could be harvested with its roadless area in the timber base if the resources saved by not developing the roadless area were used for more intensive timber management on the area with roads. Secondary objectives were to estimate the employment, financial, environmental, and multiple use implications if such a policy were adopted. The intent was to do the analysis using approaches that closely simulate how such a policy would be implemented under current Forest Service regulations and planning approaches. Alternatives that change policies unrelated to the primary question were beyond the scope of the study. Thus, the analysis was done within the current policy constraints relating to timber flows, water quality, rare and endangered species, sustained yield, and other multiple use values.

Seven western National Forests were chosen for study. The results for three Pacific Northwest Region National Forests--the Siskiyou, Umatilla, and Willamette--are reported here.

For each study Forest the hypothesis was tested by calculating two harvest levels: one with Forest planned levels of intensive timber management and with the entire roadless area available for timber harvest (the base alternative) and one with the roadless area withdrawn and funds saved by not building roads available for further intensifying timber management on the remaining land (the reallocation alternative). Additional harvest levels were calculated to provide a more complete comparison of the results, and discussions of the alternative harvest levels for each Forest are included. The major conclusions of the timber harvest analyses are:

1. The harvest that could be programed in the first decade with th entire roadless area included in the timber base could not be achieved on any study Forest when the roadless area was withdra and the funds saved were reallocated to more intensive timber management. If only half the roadless area was withdrawn, however, the base programed harvest level could be achieved on one study Forest through reallocation of funds.
2. Potential yield was reduced on all Forests when half or all the roadless area was withdrawn.
3. The average annual chargeable harvest (recent harvest) on all study Forests is below the level that could be programed with current levels of investment and multiple use constraints with all the roadless area in the base. With half the roadless area withdrawn, the recent harvest could be maintained or exceeded o all study Forests with reallocation of funds; with all the roadless area withdrawn it could not be maintained or exceeded on any of the study Forests.
4. Reductions in potential yield on the study Forests were nearly proportional to reductions in regulated commercial Forest land acres.

The financial and employment effects of withdrawing roadless areas from timber harvest and reallocating funds to more intensive manageme of the remaining land are shown for the study Forests. The results were derived from several assumptions, including the expected trends in real stumpage prices and real costs when no changes in harvest occur on any National Forest except the one being analyzed.

The effects of the key alternatives on present net worth and recei to counties are shown. These results show that on the Willamette an Siskiyou National Forests the reductions in financial values when roa less areas were withdrawn were quite large. On the Umatilla the cha in financial values were small.

The report includes a general discussion of the trade-offs in environmental conditions and nontimber benefits (benefits from nontimber goods and services produced by the Forest) when roadless areas are withdrawn and timber management is intensified on the remaining land This discussion reveals that on the study Forests there are significant trade-offs associated with these alternatives.

Contents

Page

INTRODUCTION 1
  Key Question 1
  Selection of Study Forests 2

DESCRIPTION OF THE STUDY FORESTS 3
  Siskiyou National Forest 3
    Location 3
    Physical Characteristics 4
    Resources. 4
    The Roadless Situation 5

  Umatilla National Forest 5
    Location 5
    Physical Characteristics 5
    Resources. 6
    The Roadless Situation 6
  Willamette National Forest 7
    Location 7
    Physical Characteristics 7
    Resources. 7
    The Roadless Situation 8

HARVEST CONSEQUENCES OF ROADLESS AREA WITHDRAWALS. . . . 8
  Calculating Harvest Consequences--Approaches and Assumptions. 8
    Land Base. 8
    Potential Yield. 9
    Programmed Harvest 10
    Reallocation of Funds. 10
  Harvest Alternatives on Study Forests. 11
    Base Alternative 12
    No Reallocation Alternative. 13
    Reallocation Alternative 13
    Partial Roadless Area Alternatives 13
  Primary Study Finding. 14
  Other Harvest Consequences 15

  Harvest Results on Study Forests 17
    Willamette National Forest 17
    Siskiyou National Forest 18
    Umatilla National Forest 21
  Generalizing Study Results to Other National Forests . 22

FINANCIAL AND EMPLOYMENT CONSEQUENCES OF ROADLESS WITHDRAWALS 23
  Assumptions Used in Financial Analysis 23
    Purpose of the Analysis. 23
    Projecting Future Trends 23
    Price Assumptions. 24
    Interest Rates and Discounting 25
    Cost Assumptions 26
  Assumptions and Procedures Used in Employment Analysis. 26
  Financial Consequences--Summary of Findings. 27
  Employment Consequences--Summary of Findings 28
  Financial and Employment Results on Study Forests. 28
    Willamette National Forest 33

Page

Siskiyou National Forest 34
Umatilla National Forest 34
Conclusions About the Financial and Employment Consequences of Roadless Area Withdrawals. 35

CHANGES IN ENVIRONMENTAL CONDITIONS AND NONTIMBER BENEFITS 35
Background 35
Present Situation. 36
Comparison of Alternatives 36
Criteria 38
Water Quality. 38
Water Quantity and Timing of Flow. 38
Soil Stability 38
Soil Productivity. 38
Forage Production. 39
Anadromous and Residential Cold Water Fish Populations 39
Wildlife Populations 39
Opportunities for Developed Recreation 39
Opportunities for Dispersed Recreation Related to Roads. 39
Opportunities for Dispersed Recreation Away from Roads 39
Visual Resources 39
Air Quality. 40
Mineral and Energy Development Opportunities 40
Siskiyou National Forest Results 40
Umatilla National Forest Results 41
Willamette National Forest Results 43

LITERATURE CITED 44

APPENDIX A - Real Stumpage Price (Dollars Per Thousand Board Feet) Assumptions Used for Study Forests 46

APPENDIX B - Annual Real Per Capita Income Growth Rate, Oregon and Washington. 50

APPENDIX C - Documentation of Road Costs and Assumptions and Silvicultural Costs for Each Study Forest. 51
Road Costs and Assumptions 52
Siskiyou National Forest 52
Umatilla National Forest 54
Willamette National Forest 55

APPENDIX D - Summary and Detailed Financial Consequences for Study Forests When Proportional Changes in Harvest on Other National Forests Are Assumed. 58

APPENDIX E - Summary and Detailed Financial Consequences for Study Forests When Constant Real Prices and Constant Real Costs Are Assumed 62

APPENDIX F - Employment Consequences for the Siskiyou, Umatilla, and Willamette National Forests, July 28, 1978 . 66

APPENDIX G - Roadless Areas in This Study, by Forests. . . 68

Introduction

The administrative and legislative branches of Government are moving toward resolution of the questions of the aggregate amount and distribution of American wilderness. The National Forests are a key element in this decision because extensive roadless areas are still available which could be designated as wilderness. Many of these areas are also desirable for other uses; thus, conflicts have arisen among different classes of users over the ultimate disposition of these lands. In view of the complex trade-offs involved and of the need to identify and measure the consequences of some proposed solutions to the problem, a study team composed of USDA Forest Service economists and forest managers was organized to study, in depth, on a few selected western National Forests the proposal that investment funds be used to intensify forest management on roaded portions of National Forests, leaving roadless areas undeveloped. The results of this study are presented in a national report.[1] The purpose of this report is to detail results for the study of Forests in the Pacific Northwest Region (Oregon and Washington) and to present and explain in more detail the data and assumptions used in the national report. Reports detailing study results for other western regions are being prepared.

KEY QUESTION

It has been suggested that reallocating dollars from building roads in the roadless areas to more intensive management of the areas where a road network has already been established would be a better use of resources. Moreover, it has been suggested that reductions of timber harvest resulting from withdrawing roadless areas from the timber base can be made up from gains that result from intensified timber management practices, such as reforestation, release, and thinning in accessible areas.

The primary objective of this study was to test the hypothesis that as much timber could be harvested from National Forest areas without harvesting from the roadless areas as could be harvested with roadless areas in the timber base, if the resources saved by not developing a road system in the roadless areas were used for more intensive timber management on the lands with roads. Other objectives were to estimate the employment, financial, environmental, and multiple use implications if such a policy were adopted. Our analysis used approaches that closely simulated how the policy would be implemented under current Forest Service planning approaches. Policy changes unrelated to the primary question were beyond the scope of the study. Thus, the analysis was done within the current policy constraints relating to timber flows, water quality, rare and endangered species, sustained yield, and other multiple use values. If some of these constraints were changed the results might be very different.

---

[1] Fight, Roger D., K. Norman Johnson, Kent P. Connaughton, and Robert W. Sassaman. Roadless area-intensive management tradeoffs on western National Forests. West. Resour. Policy Econ. Res., USDA For. Serv. Revised October 1978.

SELECTION OF STUDY FORESTS

The Pacific Northwest Region is the leading timber producing region in the Nation. Within the region the National Forest System provides a substantial proportion of the total supply of timber. At local levels, National Forest timber harvests are often crucial to community welfare. Therefore, to many people the decision of whether to manage roadless areas for timber production and/or nontimber uses is of vital concern.

We did not have the time or resources to study more than a few Forests. Several criteria were used in selecting study Forests. Data for the allowable harvest model had to be available in suitable form. The Forest had to have a significant portion of its area in roadless status, and this had to comprise a significant part of the roadless area in the region. A significant part of the Forest's potential harvest had to be in its roadless area. The Forest had to be reasonably typical of the region in its roadbuilding costs and treatment of multiple use constraints.

Based on the above criteria, three National Forests were selected for study--the Siskiyou, Umatilla, and Willamette. The procedures used and alternatives studied are documented in the following sections

The acreages used in this analysis are shown in table 1. Table 1 shows that the acreage of roadless area for this study exceeds the acreage of RARE II[2] roadless areas by a significant amount on all three study Forests. The reason is that, because the study was well underway, the land base for this study was not reduced to reflect land allocations resulting from recent land use decisions or wilderness designation in the Endangered American Wilderness Act of 1978 (U.S. Laws, Statutes, etc. Public Law 95-237, 1978).

For each study Forest the hypothesis was tested by calculating two harvest levels: one with Forest planned levels of intensive timber management and with all the Forest's roadless area available for timber harvest (the base alternative) and one with the roadless area withdrawn and funds saved by not building roads available for further intensifying timber management on the remaining land (the reallocation alternative).

Forest planned levels of intensification are levels that the Forest planners believe are likely to be funded. In some cases that is somewhat above the current funding level. Additional harvest levels were calculated to provide a more complete understanding of the results, including an alternative with half the roadless area withdrawn from timber harvest. The report includes a discussion of the alternative harvest levels for each Forest.

---

[2] RARE II is an acronym for the second "Roadless Area Review and Evaluation" of land in the 187-million-acre National Forest System.

Table 1--National Forest land areas

Item	National Forest		
	Siskiyou	Umatilla	Willamette
		Thousand acres	
Total National Forest System land on the Forest	1,092	1,394	1,675
National Forest System land in the roadless area[1]	436	435	280
National Forest System land in RARE II areas[2] (net acres)	340	413	174
Regulated commercial forest land (CFL) on the Forest[3]	758	716	1,171
Regulated CFL in the roadless area[3]	275	158	195
Regulated CFL in first half of roadless area withdrawn[4]	122	91	85
National wilderness and wilderness study	109	177	265

[1] Total roadless area acreage used in this study.

[2] RARE II is an acronym for the second "Roadless Area Review and Evaluation" of and in the 187-million-acre National Forest System.

[3] Regulated commercial forest land is the land included in the determination of the harvest levels used in this study.

[4] This represents the CFL acres removed from the timber base when 50 percent of roadless areas are withdrawn from further development.

Description of the Study Forests

This section will characterize the study Forests and briefly describe the roadless area situation on each Forest.

SISKIYOU NATIONAL FOREST

Location

The Siskiyou National Forest is located in the extreme southwest corner of Oregon with a small extension into California. The Forest covers a major portion of the Siskiyou Mountain range which joins the Cascade Mountains on the east with the Coast Ranges on the northwest. Parts of Coos, Curry, and Josephine Counties in Oregon and Del Norte County in California lie within its boundaries.

Physical Characteristics

The Siskiyou Mountain area is a region of rugged topography with deeply dissected mountainous areas with no particular orientation of the valleys and ridges. Elevations range from near sea level to almost 6,000 feet. The climate on the west side of the Siskiyou Mountains is strongly influenced by the Pacific Ocean. Rainfall ranges from 80 to 90 inches along the coast to 120 inches at higher elevations. Precipitation mostly occurs during 9 months of the year; there is little rainfall during the summer. On the east side of the Siskiyous, the climate is characteristically hot and dry during the summer; precipitation for the year averages 30 inches.

The vegetation on the Siskiyou National Forest is part of a transition zone where Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) an western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) vegetative types found in the forests to the north become mixed with Douglas-fir and hardwoods commonly occurring in northern California. Variable soils and a diverse climate on the Siskiyou create many ecosystems where over 1,400 plant species may be found. Douglas-fir is the predomina species; almost 74 percent of the total forest timber volume is in Douglas-fir. Pines and hardwoods typically occupy many of the dry sc slopes and areas on the east side of the Siskiyou Mountains. One of the most important factors on the Siskiyou has been repeated fires th have left approximately 75,000 acres of higher site and 46,000 acres lower site lands occupied by low value hardwoods or brush. These are have the potential of supporting commercial stands of conifers.

Resources

Forage resources are divided into grasslands and transitory range Grasslands owe their existence to shallow-soil depths. Transitory ranges exist for a few years after fire or timber harvest. The estimated transitory range potential, based on full timber utilization (on a sustained yield basis) and grazing of slopes below 45 percent, is 4,000 animal unit months (AUM's). Present use of 2,350 AUM's doe not include transitory range; thus, the total potential is 6,350 AUM

There are 25 developed recreation sites with a capacity of 1,620 pe at one time on the Forest. In 1975 total visitor days for recreatio uses numbered 806,000. Use is categorized by use of facilities rath than activity. Use of general undeveloped areas was highest at 35 percent; roads for recreation, 25 percent; rivers and streams, 19 pe cent; campground and picnic sites, 14 percent; and others, 7 percent

Timber inventory statistics for the Siskiyou show a volume of 15,866.6 million board feet or 3,293.3 million cubic feet. The regulated allowable cut was established at 190.9 million board feet per year in 1962. This was decreased to 188.3 million board feet in Jun of 1974. In addition to the regulated cut, 3.0 million board feet per year of unregulated commercial thinning volume was planned for sale when market conditions permitted.

Water on the Siskiyou National Forest drains primarily into the Rogue River Basin. The water originating within the Siskiyou is of high quality. The major water quality problems are high temperature in the summer and high turbidity during spring runoff. Water quanti problems exist in some streams. Low summer flows contribute to excessive water temperatures. High winter flows may cause channel or bank erosion.

Many wildlife species are found on the Siskiyou. The Forest contains some 64 species of mammals, over 150 species of birds, and some 33 species of reptiles and amphibians. Fisheries are an important resource on the Siskiyou. The rivers of the Forest contain large runs of commercially important fish. Commercial salmon produced on the Siskiyou contributes heavily to retail markets nationwide.

The Roadless Situation

There are approximately 1,092,000 National Forest System acres on the Siskiyou National Forest as shown in table 1. There are 72,250 acres of other ownerships within the boundary; 6,426 acres in Research Natural Areas, Scenic Areas, etc., 76,200 acres in the Kalmiopsis Wilderness before passage of the Endangered American Wilderness Act (U.S. Laws, Statutes, etc. Public Law 95-237, 1978). Of the total National Forest System land, 69 percent was considered regulated commercial forest land for this study. The National Forest System acreage in the roadless area for this study was 435,537 acres (96,000 acres more than the RARE II inventory), of which 63 percent was considered to be regulated commercial forest land. Differences in roadless area acreages between our study and the RARE II inventory exist primarily because of wilderness designations in the Endangered American Wilderness Act of 1978 which was passed after our study was well underway. The average volume of chargeable harvest for the past decade was about 38 million cubic feet per year.

UMATILLA NATIONAL FOREST

Location

The Umatilla National Forest lies in the Blue Mountains range and is located in the northeastern corner of Oregon and in the extreme southeastern corner of Washington. Parts of Asotin, Columbia, Garfield, and Walla Walla Counties in Washington and of Baker, Grant, Morrow, Umatilla, Union, Wallowa, and Wheeler Counties in Oregon lie within the Forest's boundaries. Nearby communities with populations in excess of 1,000 persons are Walla Walla and Pomeroy in Washington and Pendleton, La Grande, and Heppner in Oregon.

Physical Characteristics

The Blue Mountains vary from undulating plateaus to steep, rugged mountains. Elevations on the Forest range from 1,900 to 7,936 feet. The climate of the Forest is temperate and semiarid, although wide variations in temperature and precipitation occur over the elevational ranges. Annual precipitation averages 20 inches at lower elevations and 55 inches at higher elevations.

Four major vegetational zones have been identified for the Blue Mountains. The western juniper (*Juniperus occidentalis*) zone occurs on dry sites at lower elevations; annual precipitation is from 8 to 10 inches. The ponderosa pine (*Pinus ponderosa*) zone lies between 2,900 and 4,900 feet; annual precipitation is between 15 and 30 inches.

The grand fir (*Abies grandis*) zone, the most extensive zone in the Blue Mountains, occurs from 4,900 to 6,600 feet in elevation. The subalpine fir (*Abies lasiocarpa*) zone is the highest forested zone, occurring at 4,500 to 7,900 feet.

Resources

Grazing was an important use of the Umatilla National Forest, even before the Forest was established. There are 67 range areas allotted to 87 permittees. These allotments cover 907,073 acres. This include most commercial forest lands. About 8,400 cattle and 13,000 sheep use these forest lands for 3 to 4-1/2 months each summer.

There are 36 developed campgrounds with 351 camping units and a capacity to camp 1,989 people at one time. In 1977 total visitor days for recreational uses numbered 1,376,000. Of this total, the fish-hunting category represented 29 percent of total use; camping, 26 percent; motorized travel, 22 percent; hiking and riding, 9 percent and others uses, 14 percent.

Timber inventory statistics for the Umatilla National Forest show a volume of 10,896.6 million board feet or 2,904.9 million cubic feet. The volume by Forest type (the predominant species) consists of approx mately 40 percent grand fir, 23 percent ponderosa pine, 15 percent Douglas-fir, 7 percent each lodgepole pine (*Pinus contorta*) and subalp fir, and 8 percent other species. The Forest presently has an annual allowable timber harvest of 135.1 million board feet in the standard a special cut categories and 50.9 million board feet in the unregulated cut category.

The headwaters of the Umatilla, John Day, Grand Ronde, Walla Walla and Lower Snake River basins originate on the Forest. The streams of the Forest provide 15 million gallons of water to almost 52,000 domestic users annually. Although Forest streams vary in flow and use, water quality is generally excellent.

The Umatilla is important in production of wildlife and fish. Portions of the Forest contain some of the most productive big game habit in Washington and Oregon. The rivers of the Forest are significant anadromous fish streams. Approximately 350 vertebrate wildlife speci can be found on the Forest.

The Roadless Situation

Table 1 shows total National Forest land on the Umatilla to be approximately 1,394,000 acres. Of this area, 716,000 acres (51 percen are regulated commercial forest land. Of the total acreage, 612,000 acres (44 percent) were in wilderness, wilderness study, or roadless status prior to passage of the Endangered American Wilderness Act (U.S. Laws, Statutes, etc. Public Law 95-237, 1978). The roadless area represented 435,000 acres (31 percent) of the total acreage, of which 36 percent was considered regulated commercial forest land. This is about 22,000 acres more than the RARE II inventory. This difference exists primarily because the inventory for this study includes part of the land designated for wilderness in the Endangered American Wilderness Act of 1978. The average volume of chargeable harvest for the past decade was about 24 million cubic feet per year.

WILLAMETTE NATIONAL FOREST

Location

The Willamette National Forest is a predominantly Douglas-fir forest, located along the western slopes of Oregon's Cascade Range. Most of the Forest is in Marion, Linn, and Lane Counties, but small portions are in Clackamas, Douglas, and Jefferson Counties. The Forest is within a 1-1/2 hr drive from Portland and a 1-hour drive from Salem, Albany, Corvallis, Bend, and the Eugene-Springfield area.

Physical Characteristics

Physiographically the Forest is divided into two geological zones, the High Cascades and the Western Cascades. Elevation is from under 1,000 feet to over 10,000 feet. The High Cascades are a region of broad, undulating plateaus, with occasional volcanic peaks. Precipitation is mainly in the form of snow--from 30 to 100 inches annually. The area has been subject to glacial and volcanic activity that has shaped its character. The Western Cascades feature a landscape deeply dissected with steep slopes and many deep, V-shaped valleys. Precipitation is mainly in the form of rain, varying from 45 inches per year on the south end of the Forest to 120 inches on the north end. The Western Cascades is one of the most productive timber producing areas in the Nation. The climate is favorable to the growth of Douglas-fir, western hemlock, and western redcedar (*Thuja plicata*), as well as other species.

Resources

The Forest is the source of many products and services, including wood, water, wildlife, wilderness, and recreation.

A total of 254,744 acres have been set aside in wilderness status. In 1975, the Forest experienced 2,069,000 recreational visitor days of use. The four wildernesses on the Forest accounted for about 15 percent of the total visitor days.

There are 18,730 acres of surface water on the Forest. Five major reservoirs that provide flood control, power generation, and streamflow regulation contribute to the Forest's surface water. In addition, the Forest has over 300 lakes and 2,500 miles of rivers and streams.

The water resource also provides a wide variety of game fish, including a significant anadromous fishery.

Wildlife in the Willamette National Forest includes a large variety of big game and small game, as well as nongame species.

Timber inventory statistics for the Willamette National Forest (1976) show a volume of 43,486 million board feet (8,865 million cubic feet) on available commercial forest lands. The major timber species are Douglas-fir, about two-thirds of the total volume; western hemlock, about 14 percent; and smaller quantities of Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), noble fir (*Abies procera*), western redcedar, and other species. The average annual level of harvest (sales) proposed for the next decade in the timber management plan will be 635.6 million board feet, which includes 30.9 million board feet of mortality salvage.

The Roadless Situation

Of the 1,675,000 acres on the Willamette National Forest, 255,000 acres (15.2 percent) of the area had already been classified as wilde ness when this study was begun. In addition 10,221 acres had been designated for wilderness study for a total of approximately 265,000 acres in either actual wilderness or wilderness study status (table 1 The total roadless area acreage on which this study was based (as of June 1977) was 280,475 acres, of which 195,000 acres (70 percent) wer classified as regulated commercial forest land (CFL). The total is 106,000 acres more than in the RARE II inventory. This difference exists primarily because we did not reduce the land base to reflect changes in land allocations in the 1977 land use plan, nor for wilder ness designations in the Endangered American Wilderness Act (U.S. Law Statutes, etc. Public Law 95-237, 1978). The average volume of char able harvest for the past decade was about 106 million cubic feet per year.

Harvest Consequences of Roadless Area Withdrawals

In this section of the paper we discuss the methods and results of pursuing the main objective of this study; i.e., determining whether as much timber could be harvested from National Forest areas without harvesting from the roadless areas as could be harvested with roadles areas in the timber base, if the resources saved by not developing a road system in the roadless areas were used for more intensive timber management on the lands with roads. Subsequent sections will discuss results for the other objectives related to financial and environment consequences.

In this section we first present the procedures and definitions used to reach the study results. Second, we define and discuss the major study alternatives. Next, we discuss the major findings, both in general and Forest by Forest. Finally, we examine possibilities for generalizing study results for use on other National Forests.

CALCULATING HARVEST CONSEQUENCES— APPROACHES AND ASSUMPTIONS

The major task of this study was to calculate the effect of roadle area withdrawals and reallocations of funds on the potential yield an programed harvest of each study Forest. We required timber managemen and inventory data and a timber harvest scheduling algorithm. The management and inventory data were provided by the timber management staff of each study Forest. The timber harvest scheduling computatio were done by Johnson, using an optimal timber harvest scheduling algorithm, model II (Johnson and Scheurman 1977).

Land Base

Following RARE I (the first Roadless Area Review and Evaluation), the areas selected for wilderness study were placed in a deferred cat egory and removed from the base on which timber harvests were calcula

Existing timber management plans typically assume that all roadless areas except selected study areas will be available for timber harvest. We used these assumptions in calculating the base alternative.[3] After our study was begun, the Endangered American Wilderness Act of 1978 (U.S. Laws, Statutes, etc. Public Law 95-237, 1978) designated substantial parts of roadless areas as Wilderness on the study Forests. Although these areas have been removed from the RARE II inventory, they are assumed to be available for timber harvest in the base alternative used in this study. Because of these differences, the acres of roadless areas included in the base alternative do not correspond to the RARE II inventory. That does not seriously detract from the usefulness of our results, however, since one purpose of this study is to illustrate the trade-offs that may occur on many National Forests rather than to analyze a specific policy on a particular Forest.

Potential Yield

The potential yield for a National Forest is a ceiling on the volume of timber that may be sold from the Forest for the next 10 years. According to the Forest Service Manual, the potential yield:[4]

> is the maximum harvest that could be planned to achieve the optimum perpetual sustained-yield harvesting level attainable with intensive forestry on regulated areas considering the productivity of the land, conventional logging technology, standard cultural treatments, and inter-relationship with other resource uses and the environment.

Conventional logging technology and standard cultural treatments include all applicable developed and proven systems for intensive management, whether or not they are currently economical or in general use in the area. Excluded are the effects of intensive activities, such as fertilization and irrigation that currently remain speculative or with unquantified benefit over large portions of the country.

In practice, there is some range of interpretation of this definition. On some Forests, the potential yield is designed in full recognition of all current constraints and is a rate of harvest that could be immediately implemented--in some cases, it is being harvested now. On other Forests, the potential yield is a rate of harvest that might be achieved within a decade because the harvest constraints can be reasonably expected to be overcome during that time. On still other Forests, the potential yield rate of harvest is unlikely to be achieved within a decade because the harvest constraints are unlikely to be overcome.

Potential yield for each study Forest was calculated with (1) all the roadless area in the timber production base, (2) half the roadless area withdrawn from the base, and (3) all the roadless area withdrawn. Since potential yield is based on full funding for feasible intensive management practices, the potential always goes down when the land base is reduced, as when all or part of the roadless area is withdrawn from the timber harvest base. Even with full funding, however, the potential yield level cannot always be immediately programed for harvest. When there are areas that can only be harvested after some technical, biological, or economic problems are resolved, the potentia yield may not be immediately realized, even with full funding. It is a useful benchmark, however, because it represents a goal National Forest planners believe can be attained in the future. (For a more complete definition of potential yield, see Forest Service Manual 2415--footnote 4).

---

[3] Our land base and roadless areas were as of June 1977.

[4] USDA Forest Service Manual, 2415.41, Potential yield. May 1972.

All harvest levels calculated in tests of the study hypothesis are only for live, green material from regulated areas. They exclude material from unregulated areas and all dead material.

Programed Harvest

Another set of calculations for each study Forest was the programed harvest with (1) the total roadless area in the timber production base (2) half the roadless area withdrawn from the base, and (3) the total roadless areas withdrawn. The programed harvest for a Forest is that part of the potential yield scheduled for sale during a specific year. It is based on current stumpage prices, funding, silvicultural practic and multiple use considerations. With half and all the roadless area withdrawn, we calculated a programed harvest both with and without reallocation of funds to intensive management.

Programed harvest levels were developed by calculating a nondeclining harvest level with assumptions used by the Forests in their most recent planning effort. The resulting harvest level and sequence was taken back to the Forest team of resource specialists to verify that it was a feasible schedule. In many cases the schedule was not feasible, and the team developed constraints to make it feasible. The harvest schedule was then recalculated with those constraints.

The programed harvest with half the roadless area withdrawn and no reallocation of funds was designed to permit intensive management activities to continue at a level not to exceed that in the base programed harvest. The alternative--half the roadless area withdrawn and reallocation of funds to intensive management--was calculated by permitting additional intensive management above the Forest planned level of management to the limit of funding represented by the savings available from not developing half the roadless area.

Reallocation of Funds

To estimate the amount of funds to be reallocated to intensive management, we used the costs of road construction, reconstruction, and maintenance necessary to fully develop the roadless area. These costs are described for each study Forest in appendix C and in table 2. The amount to be reallocated would be equal to the costs avoided by not developing the roadless area, less any increased costs incurred in the currently accessible area as a result of not developing the roadless area. For example, on the Willamette National Forest it would be necessary to build additional roads in currently accessible areas to connect with roads in other accessible areas that would have been linked if roads had been built in a roadless area.

Table 2--Initial stumpage prices and road data

Item	National Forest		
	Siskiyou	Umatilla	Willamette
Total miles constructed to complete road system in roadless areas	664	657	488
Total construction costs (dollars)	56,000,000	35,700,000	56,800,000
Cost per mile (dollars)	84,300	54,400	116,400
Construction (percent):			
1st decade	20	40	32
2d decade	30	25	35
3d decade	30	20	21
4th decade	20	15	12
Road miles per section in roadless areas:			
Regulated commercial forest land (acres)	1.5	2.7	1.6
Total National Forest (acres)	1.0	1.0	1.1
Reconstruction cost per mile (dollars)	19,300	7,200	28,000
Reconstruction cycle (years)	20	20	20
Maintenance costs (dollars per mile per year)	1,400	900	600
Stumpage price (dollars per 1,000 board feet):			
Accessible area	183	64	208
Roadless area[1]	158	53	204
Roadless area[2]	156	43	177

[1] Contains the half of the roadless area most likely to remain in the timber base.

[2] Contains the half of the roadless area most likely to remain roadless.

The cost saving consists of two components: (1) purchaser credits that would be generated from timber sale receipts in the roadless area and (2) road funds appropriated by Congress. If the roadless area is not developed, the purchaser credits are not generated. The cost saving then is not in the form of money that the Forest Service has available for reinvestment. This fact does not influence the study results, but it does mean that the reallocation alternatives could be implemented only if Congress decided to reinvest and appropriated additional money to be allocated to intensive management.

HARVEST ALTERNATIVES ON STUDY FORESTS

Five alternatives were examined for each study Forest. For each alternative there is a potential yield and a programed harvest. All figures presented exclude material from unregulated areas and all dead material. Because of this, our figures may differ from some published figures for the study Forests. Alternatives are summarized in table 3.

Table 3--Summary of alternatives used in analysis

Alternative	Proportion of roadless area available for timber management	Funds reallocated to more intensive timber management	Harvest calculations		
			Programed harvest	Potential yield[1]	
Base	All	No	X	X	
50 percent of roadless area withdrawn from timber harvest	Half	No	X	X	same
50 percent of roadless area withdrawn from timber harvest; funds reallocated to more intensive timber management	Half	Yes	X	X	
100 percent of roadless area withdrawn from timber harvest	None	No	X	X	same
100 percent of roadless area withdrawn from timber harvest; funds reallocated to more intensive timber management	None	Yes	X	X	

[1] Bracketed data were obtained with 1 computer run.

Base Alternative

The base alternative simulated a timber management plan in which roads would be built and timber harvested over all the roadless area. This alternative incorporated current plans for timber management, road construction, multiple use constraints, and funding levels. We wanted to know the programed harvest and the potential yield of this simulated plan. We were also interested in whether the volume actually sold recently was significantly different from the programed harvest.

It was essential to have a clear picture of the road system that would be needed to implement this simulated plan. We needed to know the road program that would be planned for the roadless area so as to determine the savings from not building those roads. We needed to know the road program that would be planned in the accessible area so as to determine the incremental costs associated with changes from the base program. We also needed information on the level of forest management practiced and on employment and nontimber impacts under the base alternative.

The programed harvest of the base alternative approximates the programed harvest of live, green timber in an updated timber management plan where we assume the Forest planned level of intensive management and silvicultural practices, current multiple use considerations, and current stumpage prices. We also assume the regulated commercial forest land shown in table 1 is the land base for regulated timber production and that there are no restrictions on timber harvesting in the roadless area other than those normally associated with environmental and multiple use considerations. Although Forest Service managers normally think of programed harvest as pertaining to a specific year, we use a broader definition of the term. We use it to refer to an annual harvest over several decades that is consistent with the assumptions and constraints that initially apply.

The potential yield of the base alternative approximates the potential yield of an updated timber management plan with the land base as above. In most cases the silvicultural practices included are those that forest managers would include in a new plan for the Forest.

No Reallocation Alternative

The purpose of this alternative was to determine what would happen to future harvest on a Forest if the roadless area were removed from the timber base with no increase in intensive management. Under this alternative no increase in management intensity was permitted, and the multiple use adjustments were modified as necessary to reflect the reduced land base. As before, the desired result was a simulated programed harvest and potential yield.

Reallocation Alternative

The purpose of the reallocation alternative was to determine what would happen to harvests if we excluded the total roadless area from the timber base, but made available for timber management the resources that are saved by not developing the roadless area.

Except for the land base and the budget, this alternative had the same policy constraints as the previous alternatives. The new budget constraint for each decade was the implied level in the base alternative, plus the amount of money saved by not roading the roadless area.

Partial Roadless Area Alternatives

On each National Forest, the total roadless area is composed of a smaller subdivision of individually identified roadless areas. There is reason to believe that the harvest impact of these individual roadless areas varies widely, depending on the characteristics of the area. Because of these impacts that are probably variable, it would be useful to repeat the no reallocation and reallocation alternatives with a portion of the roadless area excluded. This would allow some interpolation of the results for policy alternatives that involved partial exclusion of roadless areas.

The approach for partial exclusion of roadless areas was to remove half the total roadless area from the timber management land base. The half to be removed was selected in cooperation with National Forest personnel familiar with the roadless area situation on each Forest.

Factors that were considered in determining removal included quality of areas for wilderness or other nontimber uses, public interest, congressional and administrative interest, manageability, and the dire and indirect costs of permanent roadless designation. In general, the allocation of areas selected to remain roadless and those to be remove from roadless status was done by individually identified units. Division of individual roadless areas was avoided where possible. The approximate 50-percent division was based on total National Forest acres in all roadless areas. There was no attempt to select the half on the basis of commerical forest land acreage, volume of standing timber inventory, or potential for production. Appendix G lists by name the roadless areas included in the study for each Forest and the roadless areas withdrawn from the timber base in the 50-percent alternative.

PRIMARY STUDY FINDING

The harvest that could be programed in the first decade with all the roadless area included in the timber base could not be achieved on any study Forest when all the roadless area was withdrawn and the funds saved were reallocated to more intensive timber management (table 4); if only half the roadless area was withdrawn, however, the base programed harvest level could be achieved on the Willamette National Forest through reallocation of funds.

When all the roadless area is withdrawn, funds for intensive manag ment are not the principal constraint limiting the harvest that can b programed in the first decade. There are two reasons for this.

First, on the Siskiyou and Willamette National Forests the protection of environmental and multiple use values imposes a constraint on the extent of harvesting when all the roadless area is withdrawn whic restricts the level of harvest to the reduced land base. This constraint is becoming progressively more important as the current ban o logging in roadless areas continues to limit the harvest to this reduced base. Where environment and multiple use are the principal contraints, increases in harvest from additional intensive management wi be delayed to future decades.

Second, on the Umatilla National Forest, although funds for intens management are available, a lack of unfunded management activities af all the roadless area is withdrawn does limit the harvest.

With half the roadless area withdrawn, environmental and multiple use constraints on harvest acreage still prevent an increase in the harvesting level on the Siskiyou National Forest. On the Umatilla an Willamette National Forests, however, the funding saved can be used t increase harvests. On the Umatilla this increase is slight because there are few opportunities. On the Willamette the increase is sufficient to more than make up for the decreased harvest resulting from withdrawal of half the roadless area.

Details on each study Forest are provided in a following section.

Table 4--Alternative harvests and recent harvest on study Forests[1]

Alternatives	National Forest		
	Siskiyou	Umatilla	Willamette
	Million cubic feet per year		
Programed harvest:			
All roadless areas in the timber base[2]	44.9	26.2	115.4
50 percent of roadless area withdrawn from timber base; no reallocation of funds	39.1	23.9	109.9
50 percent of roadless area withdrawn from timber base; reallocation of funds	39.1	24.0	118.6
100 percent of roadless area withdrawn from timber base; no reallocation of funds	30.0	21.7	102.8
100 percent of roadless area withdrawn from timber base; reallocation of funds	30.0	21.7	102.8
Potential yield:			
All roadless areas in the timber base[2]	59.4	31.2	157.4
50 percent of roadless area withdrawn from timber base	51.9	27.3	146.3
100 percent of roadless area withdrawn from timber base	39.8	24.3	134.1
Recent harvest	38	24	106

[1] Programed harvests and potential yields exclude material from unregulated areas and all dead material. Recent harvest is the average annual chargeable harvest for 1968-77; it excludes harvests from unregulated areas and generally excludes salvaged dead material considered to be endemic mortality.

[2] For the base alternative, we not only assume that all the roadless areas are in the timber base but also assume that there are no restrictions on entering the roadless areas.

OTHER HARVEST CONSEQUENCES

(1) The recent harvest[5] on all study Forests is below the level that could be programed with currently planned investment levels and current multiple use constraints with all the roadless area included in the base. With half the roadless area withdrawn, the recent level of harvest could be maintained or exceeded on all study Forests with reallocation of funds saved by not building roads on the withdrawn area and with all the roadless area withdrawn it could not be maintained or exceeded on the study Forests (table 4). Recent harvests generally were less than could now be programed with all the roadless

---

[5] Recent harvest is the average volume of chargeable harvest cut from the Forest for the past 10 years. This definition corresponds most closely with the harvest calculations which include only volumes to local merchantability limits from live green trees on regulated lands.

area in the base, for a variety of reasons. For example, on the Umatilla National Forest the recent harvest was based on a plan that was 10-15 years old; this study was based on new inventories and planning assumptions. Another example is on the Willamette National Fores where timber operators have been harvesting timber sales at a slower rate than they have been buying them, leading to a buildup in uncut, but sold, timber volume.

(2) Potential yield was reduced on all Forests when half or all the roadless area was withdrawn (table 4). These reductions were oft large.

These comparisons relate to different questions. Comparing the ba programed harvest with the programed harvest on the reduced land base is most relevant to the question of what do we give up in timber outp in the near future if we withdraw the roadless areas and intensify timber management on the remaining land. Comparing the recent harves with the programed harvest on the reduced land base is most relevant to the question of what is the impact on existing local economies if we withdraw the roadless areas and intensify timber management on the remaining land. Comparing the base potential yield with the potentia yield on the reduced land base is most relevant to the question of wh do we give up in timber output in the more distant future if we withdraw the roadless areas and intensify timber management on the remaining land.

(3) Reductions in potential yield on the study Forests were nearl proportional to reductions in regulated commercial forest land acres (table 5). This reduction as a percentage of the base potential yiel is 15 percent on the Willamette National Forest, 22 percent on the Umatilla; and 33 percent on the Siskiyou. Because there are various kinds of constraints on programed harvest levels, the reductions in programed harvest vary somewhat more than potential yield in comparis with the reductions in regulated commercial forest land.

Table 5--Comparison of reductions (in percent) in regulated commercial forest land (CFL) acres and harvest volume when all the roadless area is withdrawn on study forests

Item	National Forest		
	Siskiyou	Umatilla	Willamette
Regulated CFL acres in the roadless area	36	22	17
Base potential yield from the roadless area	33	22	15
Base programed harvest from the roadless area without reallocation of funds	33	17	11

HARVEST RESULTS ON STUDY FORESTS

Willamette National Forest

Figure 1 illustrates that potential yield is reduced when half or all the roadless area is withdrawn by 7 and 15 percent, respectively. With respect to programed harvest, figure 1 illustrates that when 100 percent of the roadless area is withdrawn, none of the reduction can be offset. When 50 percent of the roadless area is withdrawn, however, the reduction in programed harvest can be more than offset by reallocating funds to more intensive management of the remaining land. This happens because the Willamette has a substantial amount of unfunded opportunities for cultural treatment. Some discussion of these results are in order.

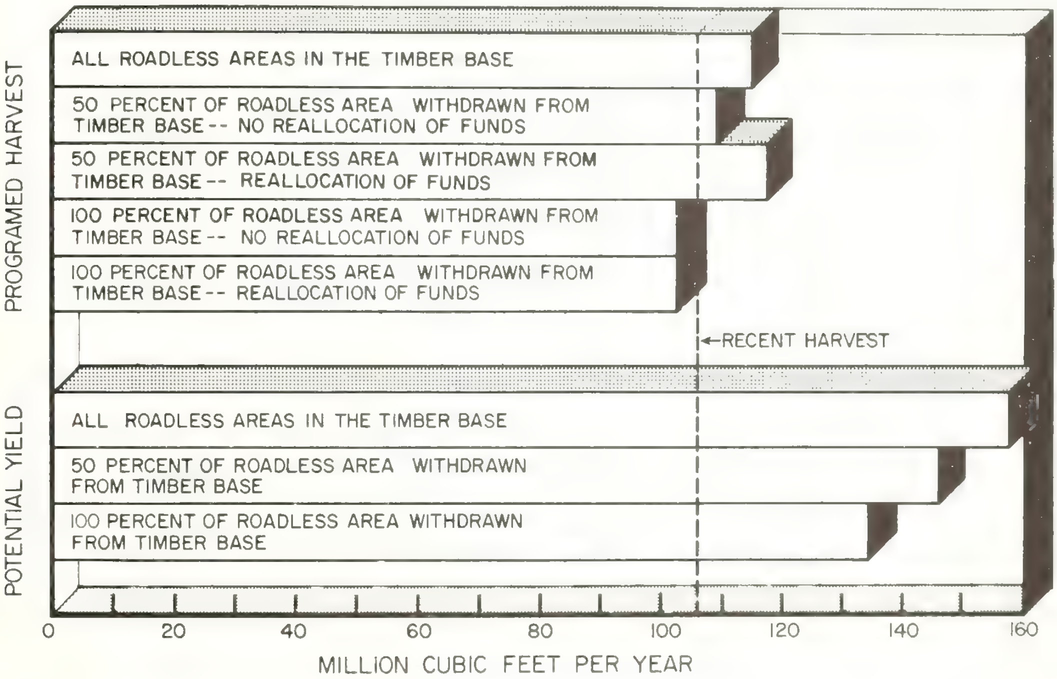


Figure 1.--Alternative harvest levels for the Willamette National Forest. Harvests can be converted to board feet, local scale, by using the board-foot/cubic-foot ratio 5.4 for programed harvests and 5.5 for potential yields.

It is important to realize that the primary constraint holding down the base programed harvest is lack of funds and manpower for investments in intensive management practices. If, however, this constraint were overcome, the next thing limiting the harvest would be a constraint on the number of acres of regeneration harvest imposed to protect non-timber resources, especially soil, water, fish, and wildlife resources. Recently, concentration of timber cutting in the accessible area, caused by the moratorium on harvesting in roadless areas has caused this constraint to assume greater importance. If all roadless areas are withdrawn from the timber base, a number of decades, perhaps five, would have to pass before assumed budgets again became a primary constraint on timber harvest.

Table 6 illustrates that with no constraints on the budget the firs decade harvest is 130 million cubic feet per year with all roadless areas in the base, 119 million cubic feet per year with half the roadless area withdrawn, and 103 million cubic feet per year with all the roadless area withdrawn. The regeneration harvest constraint limi the harvest level in these cases.

Table 6 shows that, when budgets are constrained and 50 percent of the roadless area is withdrawn, the harvest is limited to 110 million cubic feet. This can be increased to 119 million cubic feet if funds for intensive management from not building roads in the roadless area are provided. Table 6 also shows that, when all the roadless area is withdrawn, the harvest is limited even with no budget constraint to 103 million cubic feet per year. In this case the budget is limited by environmental and multiple use restrictions that constrain regeneration harvest acreage.

After a number of decades have passed and the problems caused by concentrating cutting in the area with roads have been overcome, the harvest with reallocation of funds can be increased on the reduced land base. Table 6 shows that these levels, with half or all the roadless area withdrawn, might approach 126 million and 116 million cubic feet per year, respectively.

The potential yield shown (table 6) is a goal possibly attainable sometime in the future when marginal land problems have been solved and gains from genetic improvement have been incorporated into programed harvest calculations.

Previous analyses, such as Kutay's[6] have focused largely on these longrun effects of reallocation of road savings. We now know, howeve that this approach cannot be expected to accurately estimate the imme ate effects of withdrawing roadless areas in cases where the budget for intensive management will not be the principal constraint on harvest when the land base is reduced.

Siskiyou National Forest

Figure 2 shows that, when either 50 percent or 100 percent of the roadless area is withdrawn from the timber base, none of the reductio in programed harvest can be offset through reallocation of funds to more intensive management of the remaining land.[7] Concerns about the effects of timber harvest on other resources are similar to those fou on the Willamette National Forest. On the Siskiyou, however, even th base programed harvest and the programed harvest with 50 percent of t roadless area withdrawn are constrained by the need to protect other resources. Therefore, reallocating the road savings to more intensiv management of the remaining land will not increase the shortrun harve because it is the regeneration harvest acreage constraint and not the budget that limits harvesting. On the Siskiyou as is the case on the Willamette, it can be anticipated that the harvest could increase somewhat in future decades (table 7).

---

[6] Kurt Kutay. Oregon economic impact assessment of proposed wilderness legislation. April 1977.

[7] The base programed harvest exceeds the recent harvest primarily because the current planning effort assumes that funding for much of the intensive management opportunities will continue to be forthcoming. The recent harvest was based on the Hanzlik (1922) formula and did not recognize growth on future stands.

Table 6--Willamette National Forest programed harvests and potential yields for the study alternatives under various assumptions

Item	Base	50 percent of roadless area withdrawn from the timber base		100 percent of roadless area withdrawn from the timber base	
		No reallocation of funds	Reallocation of funds	No reallocation of funds	Reallocation of funds
			Million cubic feet per year[1]		
Maximum 1st decade programed harvest--no constraints on budgets	130	NA	119	NA	103
Maximum 1st decade programed harvest--budgets constrained	115	110	119	103	103
Programed harvest level that might be built up over next 50 years with budget constraint	115	110	126	103	116
Potential yield	157	NA	146	NA	134

NA = not applicable.

[1] Excludes dead and unregulated volume.

Table 7--Siskiyou National Forest programed harvests and potential yields for the study alternatives under various assumptions

Item	Base	50 percent of roadless area withdrawn from the timber base		100 percent of roadless area withdrawn from the timber base	
		No reallocation of funds	Reallocation of funds	No reallocation of funds	Reallocation of funds
			Million cubic feet per year[1]		
Maximum 1st decade programed harvest--no constraints on budgets	45	NA	39	NA	30
Maximum 1st decade programed harvest--budgets constrained	45	39	39	30	30
Programed harvest level that might be built up over next 50 years with budget constraint	54	42	46	34	36
Potential yield	59	NA	52	NA	40

NA = not applicable.

[1] Excludes dead and unregulated volume.

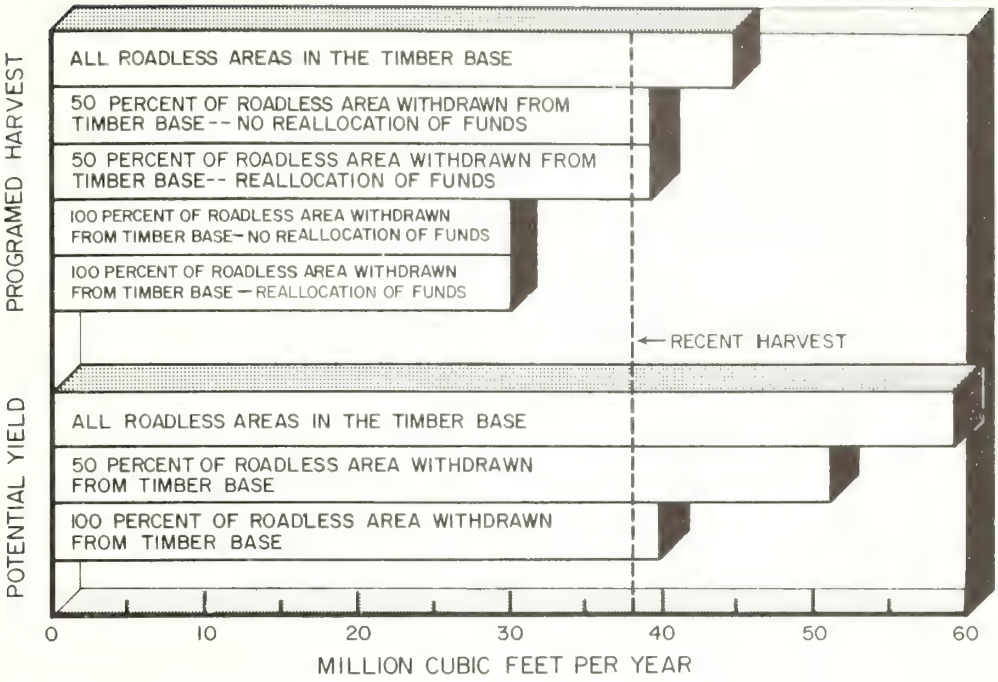


Figure 2.--Alternative harvest levels for the Siskiyou National Forest. Harvests can be converted to board feet, local scale, by using the board-foot/cubic-foot ratio 4.8.

Figure 2 also shows that the potential yield is reduced when half or all the roadless area is withdrawn (13 and 33 percent, respectively). Like the Willamette, however, the potential yield is a goal that is possibly attainable sometime in the future when marginal land problems have been resolved and genetic gains are included in programed harvest calculations.

Umatilla National Forest

Figure 3 shows that when roadless areas are withdrawn, there is virtually no opportunity to offset any of the reduction in programed harvest through reallocation of funds to more intensive management of the remaining land.[8] With all roadless areas in the base, funds for precommercial thinning slightly limit the harvest. When half the roadless area is withdrawn, the opportunities to precommercially thin are reduced to little more than the number of acres treated in the base programed harvest. This small amount of precommercial thinning results in a slight increase in programed harvest with reallocation. When all the roadless area is withdrawn, the opportunities to do precommercial thinning are reduced below the amount treated in the base programed harvest. Therefore, there are no opportunities for treatment and no response to reallocation.

---

[8] The base programed harvest exceeds the recent harvest primarily because increased investments in precommercial thinning have resulted in higher investment assumptions than were used in the previous plan.

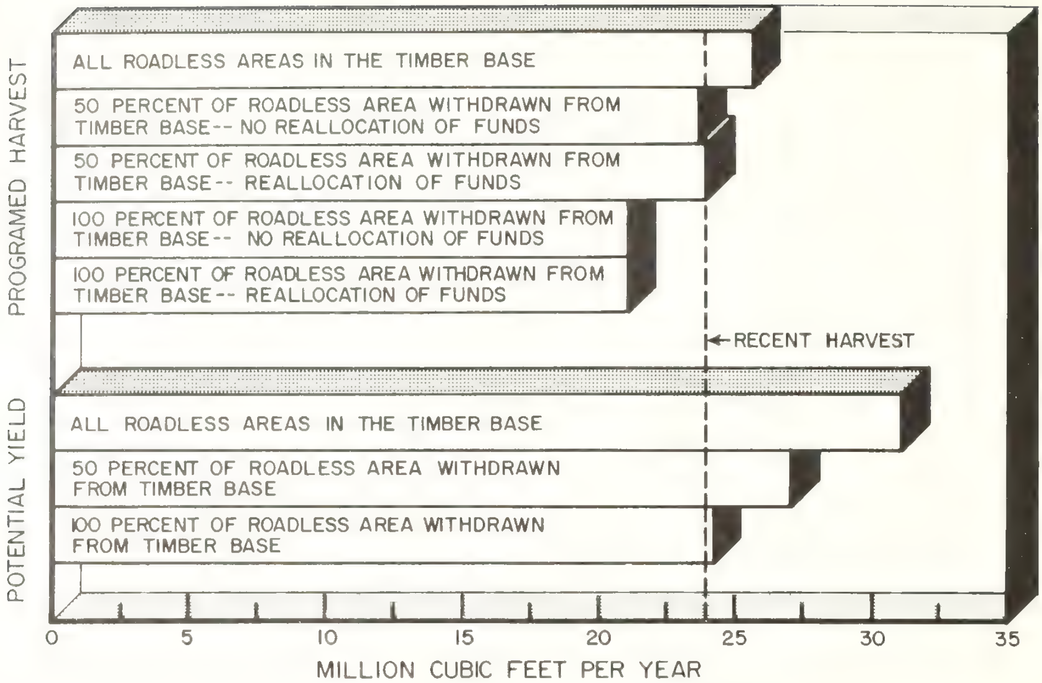


Figure 3.--Alternative harvest levels for the Umatilla National Forest. Harvests can be converted to board feet, local scale, by using the board-foot/cubic-foot ratio 6.4.

Figure 3 also shows that the potential yield was reduced from a bas of 31 million cubic feet per year to 24 million, or 22 percent when 100 percent of the roadless area was withdrawn. Notice that potential yield when 100 percent of the roadless area was withdrawn is lower tha the base programed harvest. With 50 percent of the roadless area withdrawn, potential yield is reduced 13 percent but still remains at a higher level than the base programed harvest.

GENERALIZING STUDY RESULTS TO OTHER NATIONAL FORESTS

The study Forests are not a scientific "sample." Therefore, no firm, quantitative conclusion can be drawn about other Pacific Northwest National Forests. This study, however, does suggest that there may be some ability to substitute management intensification for roadless area volume on other National Forests, especially if withdrawals include up to half rather than all the roadless area.

Identifying National Forests that are likely candidates for this substitution is made difficult by the nature of the constraints that hold down the harvest as the land base changes. For example, when all roadless areas are included in the Willamette's harvest calculation, the budget for management intensification is the primary constraint holding down harvest; however, when all roadless areas are excluded from the Willamette's harvest calculation, the number of acres allowed for regeneration harvest becomes the primary constraint holding down the harvest. This situation makes it extremely difficult or perhaps impossible to use the harvest results from the study Forests to predict the result of withdrawals of roadless areas on other National Forests. To predict the result of withdrawing roadless areas and intensifying timber management on the remaining land, we must be able to determine what the principal constraint on harvest would be with the reduced land base. In many cases that information can only be obtained by a careful consideration of some harvest calculations. For most Forests, calculations of that sort do not now exist. If one could determine that funds for intensive management would be the principal constraints with the reduced land base, it would still be necessary to have some harvest calculations to indicate the amount that the harvest could be increased through reallocation. The earned harvest from management activities on the full land base will not provide a reliable estimate because opportunities for applying management activities are normally reduced when roadless areas are withdrawn. Therefore, aside from the general conclusion that the opportunities to offset harvest reductions through investments in more intensive timber management appear to be limited, it does not appear possible to draw sound conclusions about other Forests without making harvest calculations for the alternatives as we have done.

Financial and Employment Consequences of Roadless Withdrawals

ASSUMPTIONS USED IN FINANCIAL ANALYSIS

Purpose of the Analysis

The purpose of our analysis is to explore the financial implications of some broad alternatives for allocation of roadless areas on the Siskiyou, Umatilla, and Willamette National Forests. One factor in particular, the 25 percent of gross revenues that National Forests are required to pay to counties, is a valuable financial indicator of the impact of roadless area allocations on local economies. Present net worth calculations are essential components of a national efficiency analysis. Finally, revenue and cost consequences are useful indicators of the effect of the alternatives on Forest budgets and Forest Service receipts to the United States Treasury.

We have no financial results for individual roadless areas on the Forests. We know, however, that within the broad averages used for each Forest individual roadless areas vary tremendously in timber inventories, amount of commercial forest land, productivity, and financial value.

Projecting Future Trends

Perhaps the most perplexing problem in quantifying the financial consequences of the harvest alternatives is how to account for the considerable uncertainty which exists regarding prices and costs in the future. To investigate the sensitivity of the financial results to alternative views of the future, we calculated the results with two interest rates, three assumptions about the course of stumpage prices, and two assumptions about future management costs. Real (deflated) prices, costs, and interest rates were used in the financial analysis. In terms of projecting future economic trends, "real" means that we make no attempt at projecting inflationary trends.

Our procedure for projecting future trends involves determining a current value for the item we are projecting and then estimating its future real increase, if any. The initial stumpage prices for each National Forest come from the trend in high bid prices from recent sales on the Forests. The changes in real prices come from an early version of the Resources Planning Act Timber Assessment Softwood Market Model.[9]

The average annual compound growth rate in real prices for the period 1978-2030 on Region 6 Forests is: West-side (Douglas-fir) region, 1.9 percent; east-side (ponderosa pine) region, 1.5 percent. The growth rate for prices is higher than average for the west side and east side until the year 2000, after which it slows considerably. After the year 2030, real stumpage prices are assumed to be constant.

Price Assumptions

Table 2 shows the values for initial stumpage prices and road items for each study Forest. Our assessment of stumpage prices starts with the high bid price for the accessible area. High bid is the value of stumpage as if the roads were in place. It is appropriate to use the high bid since we are accounting for road costs separately. The prices received for stumpage will be different in the roadless area from those in the accessible area because of differences in species mix, timber quality, and logging and hauling costs. These factors were accounted for when we developed separate prices on each Forest for each half of the roadless area and for the accessible area. The high bid prices for each area (table 2) were provided by each Forest and represent 1977 stumpage prices which were trended to average out recent fluctuations in stumpage markets.

In the financial analysis, we use three assumptions about the future course of stumpage prices.

The first assumption is that the stumpage price on each study Forest remains constant over time at the recent high bid levels reported by the Forests. The second and third assumptions are that real stumpage prices will rise until 2030; the difference between the second and third assumptions is in their treatment of Region 6 Forest Service harvest levels. With the second assumption no roadless areas would be withdrawn on other Region 6 National Forests and Forest Service harvest levels would follow trends assumed in the Resources Planning Act Timber Assessment Softwood Market Model (see footnote 9). The third price assumption for the Willamette and Siskiyou National Forests is the expected trend in prices if changes in harvest levels on all west-side Region 6 National Forests occur simultaneously and are proportional to the change on the Forest being analyzed. The third price assumption for the Umatilla is the expected trend in prices if there are simultaneous changes in harvest levels on all east-side Region 6 National Forests that are proportional to the changes on the Umatilla.

---

[9] Adams, Darius M., and Richard W. Haynes. 1978. A preliminary description of the 1980 Timber Assessment Softwood Market Model. Report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

For the second and third assumptions, the stumpage price for each study Forest depends on three factors: (1) regional stumpage price, (2) the quantity of stumpage harvested on the Forest, and (3) the land base (roadless areas included or not) associated with harvest. Regional price effects are determined from demand relationships which take into consideration harvest changes on private lands.

In the absence of data on harvest changes on other Forests, we consider the second assumption most realistic, and results using that assumption are highlighted in the financial results section. Results for the third price assumption are included in appendix D. These results must be viewed as a rough approximation of the financial effects on each study Forest of withdrawing roadless areas simultaneously from the other National Forests because the actual harvest changes that would take place on other Forests would not likely be proportional to the change on the Forest being analyzed. Since we cannot estimate the Region 6 change in harvest from our limited number of study Forests, we use the assumption of proportional harvest changes to illustrate the effect of this alternative.

The actual prices used in present net worth calculations and other financial results are shown for each price assumption and for each study alternative in appendix A.

Interest Rates and Discounting

Gregersen (1975) points out the importance of not confusing market rates of interest (which incorporate expected inflation) with real rates of interest. Referring to investments in private forestry, Klemperer (1976) concludes that when inflationary effects are removed from interest rates, an after-tax rate of 5 to 6 percent is competitive.

Two interest rates, 5 and 10 percent, were used in present net worth (PNW) calculations; 5 to 10 percent represent a range in interest rates which is sufficiently wide to reveal the sensitivity of the financial results to the cost of capital. The 5- to 10-percent range also avoids the difficulties of attempting to identify a single "correct" interest rate for public investment evaluation.

Present net worths shown in the financial results section and in appendixes D and E are calculated for 10 decades by the following relationship:

$$\mathrm{PNW} = \sum_{n=1}^{10} \frac{r_n \, [(1+i)^{10} - 1]}{i \, (1 + i)^{10n}}$$

where,

PNW = present net worth,

r_n = average annual net revenue received in the n-th decade,

i = interest rate (0.05, 0.10),

n = decade (1, ..., 10).

Cost Assumptions

The success of dealing with uncertainty through sensitivity analysi depends on thoughtful selection of alternative views of the future. Two assumptions about the future course of real costs were used in the financial analysis. The first assumption is that all costs will remain constant at their present levels. The second assumption is that the cost per acre for labor intensive practices will increase at the same rate as real per capita income in Oregon and Washington. Specifically, costs for regeneration, precommercial thinning, and timber sale preparation are assumed to increase at the same rate as the U.S. Water Resources Council (1974) projections of real per capita income in Oregon and Washington to the year 2020. The increase in real costs of these items is approximately 2.7 percent per year over the period 1980-2020. Costs are assumed constant after that.

All other cost items including road construction, reconstruction, and maintenance are assumed to remain constant in real terms; i.e., they will increase at the same rate as the general price level. The management and road costs for each Forest are found in appendix C. Road costs are also summarized in table 2.

The compound annual growth rate of real per capita income in Oregon and Washington for selected years between 1970 and 2020 is shown in appendix B. These growth rates are applied directly to the costs provided by each study Forest to obtain the future cost of the labor intensive practices.

ASSUMPTIONS AND PROCEDURES USED IN EMPLOYMENT ANALYSIS

We quantified the employment consequences of the harvest alternatives with the input-output (I-0) models developed as a part of the RARE II analysis. The RARE II I-0 model for each Forest is based on employment data from a multicounty area encompassing the Forest. These employment data are used to scale the national I-0 model to reflect the characteristics of the local economy.

Changes in harvest levels are directly and fully translated into changes in sales to final demand from the local wood products processing and timber supply sectors. No compensating adjustments in harvest flows from other local ownerships or nonlocal sources are recognized.

The consequences of the harvest alternatives on employment apply only to the local economies--economies for which the study Forests are an important source of forest-related goods and services. The reporte impacts are not the only consequences of the harvest alternatives on employment, and another choice for the area of employment impact would lead to a different set of results. It is at the local level, however that the effects of harvest changes and land allocation decisions take place and will be felt most heavily and the concern for impacts on employment is likely to be intense.

The employment results represent initial effects only. The difficulty of accurately assessing the future course of labor productivity and structural change within the local economy precludes a projection of the consequences for employment over several decades.

The results represent the sum of direct, indirect, and induced effects on employment resulting from the harvest changes on each Forest. The direct effect is the change in employment in the wood products manufacturing and timber supply sectors associated with changes in the sales of each sector to final demand. The indirect component consists of the changes in employment in all other sectors (with the exception of households) resulting from the changes in final demand sales of the wood products manufacturing and timber supply sectors. Not all the direct, indirect, and induced employment changes associated with changes in road construction are included in the employment results; however, correcting the results to reflect the omissions would likely add less than 10 percent to the employment impacts for each study Forest.

Increases in dispersed, nonmotorized recreation-related employment which would result from all the roadless areas remaining in a roadless status are likely to be small and, to varying degrees, offset by employment losses from decreases in dispersed, motorized recreation-related employment. No attempt is made to estimate the total effect on employment of changes in in-lieu tax payments to counties.

The magnitude of person-years of employment per million cubic feet of timber harvested differs from one Forest to another primarily because of differences in the structure of the economies located within the input-output areas. As indicated by the preceding discussion, the reported impacts on employment are probably conservative estimates of the local impacts of the harvest level-land base changes.

The actual level of timber-related employment in the local economy is based on the recent volume of chargeable harvest from the study Forest and other sources of timber. The employment consequences, which are directly proportional to the harvest changes, are quantified as deviations from the direct, indirect, and induced level of employment that is attributable to the base programed harvest. To the extent that the base programed harvest is greater than the recent volume of chargeable harvest, employment reductions stemming from harvest reductions represent decreases in opportunities to expand employment rather than decreases in the level of actual employment.

FINANCIAL CONSEQUENCES—SUMMARY OF FINDINGS

The financial and employment effects of removing roadless areas from the land available for timber management and reallocating the savings in road costs to more intensive management of the remaining land were derived for each study Forest. Using expected trends in real costs and real stumpage prices, we computed the results shown in the next section. The trend in real stumpage prices was based on the assumption that, with the exception of the National Forest for which the results were reported, there would be no harvest changes caused by roadless area withdrawals on any of the National Forests in the Pacific Northwest. Financial consequences calculated for two additional price and cost assumptions are shown in appendixes D and E and are discussed in the next section.

Table 8 shows the effects of the key alternatives on present net worth, receipts to counties, and local employment. On the Willamette and Siskiyou National Forests, the reductions in financial values were quite large when all the roadless areas were removed from the land base available for timber management. On the Umatilla, the changes were smaller. On the Willamette, when half the roadless area was withdrawn and funds were reallocated to intensify timber management on the area with roads, present net worth increased.

EMPLOYMENT CONSEQUENCES — SUMMARY OF FINDINGS

Changes in employment related to changes in timber harvest are variable between forests (table 8). This results both because changes in harvest vary and because the amount of employment per million cubic feet of harvest vary.

FINANCIAL AND EMPLOYMENT RESULTS ON STUDY FORESTS

The presentation of financial results in tables 9, 10, and 11 (also see appendixes D and E) shows the gross revenue and payments to countie for the base programed harvest. It shows the change in gross revenue, costs, net revenue, payments to counties, and present net worth[10] for reallocation alternatives compared with the base programed harvest. The change in costs associated with the reallocation alternatives has been estimated. The costs for roads in the accessible areas, administrative overhead, and many other costs associated with the base programed harvest have not been estimated. Therefore, we cannot show or

---

[10] When the Forest harvest changes are large enough to cause local price changes, present net worth is not the most relevant measure of the change in social welfare. Discounted net social benefit, or the discounted sum of consumers' and producers' surplus, is a more relevant criterion (McKean 1958, Prest and Turvey 1967). Net social benefit represents the difference between what society would be willing to forgo rather than go without the commodity (benefits) and the costs, exclusive of rents, which it must actually incur to produce the commodity. The distinction between discounted net social benefit and present net worth is crucial in the inelastic portion of the demand curve, since present net worth will increase when discounted net social benefit decreases, and vice versa. In the present case, however, demand relationships are elastic and the effects on prices at the National Forest level are so small that present net worth is a very close approximation to discounted net social benefit.

Table 8--Change in present net worth (PNW), payments to counties, and employment between the base programed harvest and the reallocation alternatives[1]

National Forest and alternative[2]	Change in PNW for 10 decades at 5-percent interest	Change in payments to counties[3]	Change in local employment related to change in timber harvest
	Million dollars	Million dollars per year	Person-years per year
Siskiyou:			
50 percent of roadless area withdrawn	-135.5	-2.0	-780
100 percent of roadless area withdrawn	-331.7	-5.2	-2,010
Umatilla:			
50 percent of roadless area withdrawn	-1.5	-.3	-251
100 percent of roadless area withdrawn	-1.9	-.6	-521
Willamette:			
50 percent of roadless area withdrawn	163.7	2.0	502
100 percent of roadless area withdrawn	-231.4	-4.0	-1,979

[1] Based on trends in real prices expected with no changes in harvest on other National Forests and expected trends in real costs.

[2] Alternatives show percent of the total roadless area withdrawn from a timber base that includes all roadless areas.

[3] Averages for the first 4 decades in 1973 constant dollars.

Table 9--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Willamette National Forest[1] [2]

Item	Base programed harvest	Change from base when 50 percent of roadless area is withdrawn	Change from base when 100 percent of roadless area is withdrawn
1. Harvest (million cubic feet per year)	115.4	3.2	-12.5
2. Gross revenue (million dollars per year)	232.2	3.1	-16.0
3. Cost of roads (million dollars per year)	NA	-1.0	-1.7
4. Cost of cultural treatments (million dollars per year)	NA	.7	-.1
5. Cost of selling timber (million dollars per year)	NA	.3	-.1
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	8.1	-14.1
7. Payments to counties (million dollars per year)	58.0	2.0	-4.0
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	163.7	-281.4
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	-45.2	-208.4
10. 1st decade average annual total employment (person-years)	18,215	502	-1,979

NA = not available.

[1] Trends in real stumpage prices expected, with no changes in harvest on other Douglas-fir region National Forests in the Pacific Northwest, and expected trends in real costs were used.

[2] Although the recent harvest on the Willamette National Forest is less than the base programed harvest, this was the result of short-term fluctuations in purchaser cutting patterns rather than changes in actual sales. Therefore, changes in revenues and employment shown represent changes from normal harvest levels.

Table 10--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Siskiyou National Forest[1] [2]

Item	Base programed harvest	Change from base when 50 percent of roadless area is withdrawn	Change from base when 100 percent of roadless area is withdrawn
1. Harvest (million cubic feet per year)	44.9	-5.8	-14.9
2. Gross revenue (million dollars per year)	67.9	-7.9	-20.7
3. Cost of roads (million dollars per year)	NA	-.7	-2.1
4. Cost of cultural treatments (million dollars per year)	NA	.2	-.7
5. Cost of selling timber (million dollars per year)	NA	-.4	-.9
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	-7.0	-17.0
7. Payments to counties (million dollars per year)	17.0	-2.0	-5.2
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	-135.5	-331.7
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	-59.8	-145.4
10. 1st decade average annual total employment (person-years)	6,067	-780	-2,010

NA = not available.

[1] Trends in real stumpage prices expected, with no changes in harvest on other Douglas-fir region National Forests in the Pacific Northwest, and expected trends in real cost were used.

[2] Because the base programed harvest exceeds the recent harvest by about 8 million cubic feet the reductions in revenues and employment with half the roadless area withdrawn represent losses in opportunities for increases rather than reductions from actual levels. About half the reductions in revenues and employment with all the roadless area withdrawn would be reductions from actual levels.

Table 11--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Umatilla National Forest[1] [2]

Item	Base programed harvest	Change from base when 50 percent of roadless area is withdrawn	Change from base when 100 percent of roadless area is withdrawn
1. Harvest (million cubic feet per year)	26.2	-2.2	-4.5
2. Gross revenue (million dollars per year)	17.1	-1.1	-2.3
3. Cost of roads (million dollars per year)	NA	-.6	-1.4
4. Cost of cultural treatments (million dollars per year)	NA	-.1	-.3
5. Cost of selling timber (million dollars per year)	NA	-.3	-.5
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	-.1	-.1
7. Payments to counties (million dollars per year)	4.3	-.3	-.6
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	-1.5	-1.9
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	.4	1.2
10. 1st decade average annual total employment (person-years)	3,067	-251	-521

NA = not available.

[1] Trends in real stumpage prices expected, with no changes in harvest on other ponderosa pine region National Forests in the Pacific Northwest, and expected trends in real cost were used.

[2] Because the recent harvest on the Umatilla National Forest is less than the base programed harvest, most of the reductions in revenues and employment with half the roadless area withdrawn represent losses in opportunities for increases rather than reductions from actual recent levels. The additional reductions when all the roadless area is withdrawn represent reductions from actual levels.

draw any conclusions about the net revenue or the present net worth of the base alternative. The first decade average annual total employment shown in tables 9, 10, and 11 for the base programed harvest represents the direct, indirect, and induced employment attributable to that volume of harvest. In all cases employment changes are directly proportional to the changes in programed harvest. More information concerning the employment consequences for the study Forests can be found in appendix F.

Financial results are included for three sets of price and cost assumptions. Results for individual Forest price and cost assumptions are shown in the text. This price assumption is the expected trend in prices for the Forest if the change in harvest on that Forest is the only change in harvest occurring on National Forests in the region. Under this assumption there are minor changes in prices caused by harvest reductions, but the changes in harvest are so small in comparison with the quantity of timber harvested in the region that the regional price of stumpage is unaffected. The cost assumption is the expected trend in real costs.

Results for the set of price and cost assumptions for the proportional change in harvest are presented in appendix D but are only summarized in the text. This price assumption is the expected trend in prices for the Forest if changes in harvest on all National Forests in the region occur simultaneously and are proportional to the change on the Forest being analyzed. This must be viewed as a rough approximation of the financial effects on this Forest of withdrawing roadless areas simultaneously from all National Forests in the region because the actual harvest change would likely not be proportional to the change on the Forest being analyzed. Since we cannot estimate the regional change in harvest from our limited number of study Forests, we use the assumption of proportional changes in harvest to illustrate the effect of this alternative. Under this price assumption, there may be substantial increases in prices caused by harvest reductions because the harvest change is large enough to affect the regional price of stumpage. The cost assumption is again the expected trend in real costs.

The third set of price and cost assumptions is constant real prices and constant real costs. These results show how the financial effects would differ if expected trends in real prices and real costs are not realized. These results are shown in appendix E.

Willamette National Forest

The financial results on the Willamette National Forest represent a Forest where the roadless area makes a sizable contribution to the timber program. Table 9 shows that changes in gross revenue, net revenue, and present net worth move in the same direction as changes in harvest.

The financial values increase when half the roadless area is withdrawn because the investment in additional intensive management increases the harvest more than the loss in land base reduces it. One cannot infer from that, however, that management of the roadless area would not be a financially attractive investment as well if there were sufficient funds to do the additional intensive management and build the necessary roads in the roadless area. This same general relationship also holds if we assume that future prices and costs will remain constant at their 1978 levels (appendix E).

If we assume that the harvests on all west-side National Forests in Region 6 change in proportion to the harvest changes on the Willamette, we would expect to observe substantial stumpage price decreases when half the roadless area is withdrawn and substantial increases when all the roadless area is withdrawn. The price decreases associated with the withdrawal of half the roadless area from the timber management bas lead to increases in present net worth which are smaller than those tha would be realized in the absence of proportional harvest changes on oth Forests. Similarly, the price increases which accompany the withdrawal of all the roadless area leads to less of a reduction in present net worth than would be realized if there were no harvest changes on other Forests.

Employment, which is directly proportional to the first decade harvest, increases by 502 person-years when half the roadless area is withdrawn and decreases by 1,979 person-years when all the roadless area is withdrawn.

Siskiyou National Forest

The financial results on the Siskiyou National Forest also represent a Forest where the roadless area makes a sizable contribution to the financial value of the timber program. Table 10 shows that changes in gross revenue, net revenue, and present net worth all move in the same direction as changes in harvest. One should note, however, that the second half of roadless area withdrawn (to make 100 percent withdrawn) contains a substantial amount more of volume (and thus revenue) than the first half. With the first half withdrawn, volume drops 5.8 millio cubic feet per year. Adding the second half to withdrawals reduces harvest another 9.1 million cubic feet to a total reduction of 14.9 millio cubic feet. Although the magnitudes are reduced, these general relationships continue to hold if we assume constant costs and prices or i we assume price trends that result with proportional harvest changes on all National Forests in the region.

Umatilla National Forest

Table 11 shows that the changes in gross revenue, net revenue, and present net worth move in the same direction as changes in harvest. Comparing the results for the alternatives, 50 percent of the roadless area withdrawn and 100 percent withdrawn, shows that the reductions in financial values are approximately proportional to the reductions in harvest. The reductions in financial values, however, are much less than for the Siskiyou and Willamette National Forests. In fact, under the constant cost and price assumption and under the "proportional harvest change" price assumption, the net revenue and the present net worth are increased when 50 percent or all the roadless area is withdrawn. Results in table 11 show a decrease in present net worth when calculated with a 5-percent interest rate and an increase in present net worth when calculated with 10-percent interest rate.

CONCLUSIONS ABOUT THE FINANCIAL AND EMPLOYMENT CONSEQUENCES OF ROADLESS AREA WITHDRAWALS

When all the roadless areas are removed from the timber management base, average annual gross revenue, county payments, and net revenue decline on the study Forests under the assumption of expected trends in real costs and prices with no withdrawals of roadless areas on other Forests in the region. The employment changes for each Forest are directly proportional to the harvest reductions. The results for present net worth, county payments, and employment are summarized in table 8.

On the Willamette and Siskiyou National Forests the reductions in financial values with all roadless areas withdrawn are quite large (table 8); on the Umatilla National Forest the changes are smaller. The total direct, indirect, and induced effects on employment when all roadless areas are withdrawn are losses of 530 person-years on the Umatilla National Forest, 1,979 on the Willamette, and 2,013 on the Siskiyou.

The financial results do not include a complete accounting of all the benefits and costs of the harvest alternatives. For example, nontimber benefits such as increased opportunities for wilderness recreation, and the nontimber opportunity costs, such as decreased opportunities for developed and roadside recreation are not included in the financial analysis because we do not now have defensible estimates of their monetary values. Changes in the direct management costs of producing the nontimber benefits and differences in forest protection costs are also not accounted for. Therefore, the financial results must be interpreted with care, and considerable attention must be directed to a subjective valuation of the nontimber consequences before one can draw firm conclusions as to the economic desirability of a particular alternative.

The financial analysis quantifies the major changes in the benefits and costs of the timber program. The results are useful measures of the impacts of the alternatives on local community employment, Forest Service payments to counties, Forest Service receipts that go to the U.S. Treasury, and Forest Service timber management budgets under alternative assumptions about the future course of prices and costs. The results are a necessary component of an efficiency analysis, but, as the above discussion suggests, firm conclusions about the efficiency implications of the alternatives require simultaneous scrutiny of the consequences on nontimber resources.

Changes in Environmental Conditions and Nontimber Benefits

BACKGROUND

This section of the report demonstrates that the roadless area issue involves many kinds of trade-offs concerning environmental conditions and nontimber benefits. The trade-offs examined are those attributable to withdrawing roadless areas from the timber base and reallocating road funds to intensify timber management on remaining areas. We focused our analysis of impacts on nontimber resources on a comparison of the alternative, 100 percent of the roadless area withdrawn with reallocation of funds, with the base alternative.

Impacts were estimated for five decades into the future for each nontimber benefit criterion. Major, minor, and neutral impacts were recognized according to their timing (decades one, two through four, and five plus), nature (adverse or beneficial), and, in the case of major adverse impacts, the costs of mitigation.

Major impacts were identified as those that exceeded the "threshold of concern," which is defined as the amount of impact that would generate one or more of these effects: (1) Create a public expression of concern or interest, (2) change long-term traditional use patterns, and (3) require funds substantially in excess of usual planning and budgeting levels to mitigate impacts to an acceptable level. Major adverse impacts, although undesirable, were within limits considered acceptable under current interpretation of multiple-use objectives.

We identified impacts by meeting with resource specialists from the various disciplines on each study Forest. We provided data on road schedules, schedules of intermediate and regeneration harvests, and acres of management activities. The specialists evaluated the differences in these data between the base alternative and the reallocation alternative in terms of nontimber benefits and ecosystem criteri Forest data were divided into a roadless portion and an accessible portion, which were evaluated separately. The evaluations of these impacts are shown in table 12. Of 16 environmental and nontimber benefit criteria, table 12 indicates the ones on which the effect is likely to be major or minor on at least one study Forest when the roadless area is withdrawn from the timber base and management intensified on the remaining land.

PRESENT SITUATION

Before discussing the impacts of withdrawing roadless areas and reallocating funds to more intensive management, we will briefly discuss the impacts of the base alternative compared with the current situation.

Since 1972 all RARE I roadless areas and some more recently identified RARE II areas have been closed to timber harvesting except where they have been allocated to such use through a completed land use plan. As a consequence, on many National Forests most roadless areas are stil unavailable for timber harvest even though they are included in the commercial forest land base, on which allowable harvests are calculated As a result, since 1972, road construction and timber harvesting have been concentrated outside the roadless areas. Adverse environmental impacts are beginning to develop and are in danger of exceeding acceptable levels on many National Forests. As the interdisciplinary teams have pointed out, there will be both beneficial and adverse impacts of going from the present condition to the base programed harvest. It is not our purpose, however, to evaluate these effects. We focus entirely on the changes expected to take place between the base programed harvest and reallocation alternative.

COMPARISON OF ALTERNATIVES

Table 12 summarizes the impacts expected if the base alternative is replaced by the reallocation alternative on the study Forests. If the reallocation alternative were adopted, the roadless area would remain roadless and the accessible area would be intensively managed in a manner consistent with timber flow, multiple use, and environmental policies. Impacts represent changes from the base alternative.

Table 12--Summary of estimated impacts associated with withdrawing the roadless area from the timber base and intensifying timber management on the remaining land on three Pacific Northwest National Forests

Criterion	Beneficial impacts		Neutral (no change from base)	Adverse impacts		Critical factors
	Major	Minor		Minor	Major[1]	
Water quality		R	A	A, R	A	Sediment
Water quantity		A, R	R, A			Acres of regeneration harvest
Waterflow		A, R	R, A	R, A		Peak flows
Soil stability		R	A	A	A	Disturbance on difficult sites
Soil productivity		R	A	A		Soil compaction and nutrients
Forage production (domestic)		A	A	R	R	Transitory range
Fish populations (anadromous)		R	A		A	Water quality, favorable habitat
Fish populations (residential)		R	A		A	Water quality, favorable habitat
Wildlife populations (game species)		R, A		A, R		Favorable habitat
Wildlife populations (threatened and endangered)	R	R	A	A		Undisturbed natural habitat
Opportunities for developed recreation		A	A	R	R	Potential development sites
Opportunities for dispersed recreation related to roads		A	A	R, A	R	Extent of road system
Opportunities for dispersed recreation away from roads	R	R	A	A		Extent of roadless areas
Visual resources	R	R	A		A	Natural appearing areas
Air quality		R	A	A	A	Extent of slash burning
Mineral and energy development		A	R, A		R	Access

---

[1] Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple use objectives.

R = at least one study Forest with this impact on the roadless area.

A = at least one study Forest with this impact on the accessible area.

Table 12 helps illustrate the trade-offs between the various criteria and between the roadless area and the accessible area within each criterion.

Our experience in this study has confirmed findings that were evident in the "Timber Harvest Scheduling Issues Study."[11] Specifically, impacts on nontimber resources are site specific; they may be variable within a Forest; and they often exhibit great variability between Forest and regions. For these reasons, we did not try to extrapolate regional impacts from the study Forests.

In the following section, the criterion impacts are identified and briefly discussed, and the results of the analysis of the impacts are presented for each Forest.

CRITERIA

Water Quality

Slope failure associated with timber harvests and roadbuilding activities--including the selection of sites, design, construction methods, and maintenance levels of roads--are critical factors affecting the present water quality levels in managed forest watersheds. Sediment introduced to forest streams determines, to a large extent, the impact on water quality.

Water Quantity and Timing of Flow

Impacts on water quantity and timing of flow are considered together here. In areas with abundant water, such as the Douglas-fir region of the Pacific Northwest, impacts on total water quantity are less important than impacts related to peak flows. On Forests adjacent to semiarid areas, quantity may be more important. In both the water-abundant and the semiarid areas, specialists expressed concern about peak flows reaching critical levels.

Soil Stability

Erosion and mass soil movement are the major soil stability problems. Both can affect water quality; in addition, mass movements can also be a threat to life and property. The risk of soil stability problems is increased by road construction and timber harvesting operations. The risk is also influenced by steepness of terrain and soil characteristics.

Soil Productivity

Soil productivity problems resulting from timber harvesting and roadbuilding activities take the form of compaction and nutrient loss. How residues are handled is usually considered the critical factor affecting nutrient levels. The frequency of timber harvests on a given site and the type of machinery used are critical factors affecting soil compaction. Careful selection of harvesting systems is one means of minimizing compaction problems.

---

[11] U.S. Department of Agriculture. 1976. Timber harvest scheduling issues study. 292 p. USDA For. Serv., Washington, D.C.

Forage Production

On western National Forests, domestic forage production usually is associated with transitory, forested ranges that are utilized during the summer grazing season. A close relationship exists between the amount of forage used and the location and terrain of the harvested acres. The terrain must be negotiable by domestic livestock and located in the proximity of existing active grazing allotments.

Anadromous and Residential Cold Water Fish Populations

Fish populations are directly related to habitat conditions, of which water quality is a critical factor. Hence, impacts on fish populations generally relate closely to impacts on water quality.

Wildlife Populations

The level of given wildlife populations is strongly influenced by the presence or absence of certain wildlife habitat types. Road construction and timber harvest activities impact habitat types by altering the number, size, age, arrangement, and species composition of timber stands that comprise a Forest.

Opportunities For Developed Recreation

Opportunities for developed recreation usually involve a relatively high density form of recreation centered around a developed site, such as a campground, boat launch, marina, etc. Frequently, the developed facility is located at or near a natural land feature, such as a lake, stream, waterfall, or scenic vista that provides an attractive setting. Manmade improvements may vary from primitive to relatively elaborate.

Opportunities for Dispersed Recreation Related to Roads

Opportunities for dispersed recreation related to roads are scattered, individual activities, usually not associated with developed areas.

Opportunities for Dispersed Recreation Away From Roads

Opportunities for dispersed recreation away from roads are backpacking, horseback riding, and various types of off-road vehicle experiences. Many of these activities involve a more primitive form of camping than is normally associated with developed or road-related dispersed recreation.

Visual Resources

In this paper the term "visual resources" refers to opportunities for viewing natural- appearing forest landscapes from a distance. Generally, a direct relationship exists between visual resources and the acres disturbed at any time. Impacts tend to be adverse in the short run following timber harvests , but they can be minimized through proper shaping of the harvest units to the natural characteristics of the land.

Air Quality

Smoke from burning slash is the principal source of air pollutants associated with timber management activities. The impact on air quality is, however, a short-term, seasonal problem that smoke management plans have largely overcome on many Forests. In the long run, increased utilization of residue and conversion of overmature forests to younger, less defective stands will reduce the need for burning slash.

Mineral and Energy Development Opportunities

At present, opportunities to efficiently develop mineral and energy resources are directly enhanced by the presence of a road system. On most forests, no other form of access is currently feasible for utilizing mineral and energy resources.

SISKIYOU NATIONAL FOREST RESULTS

If the reallocation alternative were adopted in place of the base alternative, no roads would be built and no road-related timber harvests would occur in the roadless area. In such an event, specialists on the Siskiyou National Forest anticipated one major adverse impact and three major beneficial nontimber and environmental impacts in the roadless area and three major adverse impacts and no major beneficial impact in the accessible area. The specialists also expected 11 minor beneficial impacts, 12 minor adverse impacts, and 2 neutral impacts in the roadless area and the accessible area. All these impacts are shown in table 13.

The major beneficial impacts of the reallocation alternative are on populations of threatened and endangered species, opportunities for dispersed recreation away from roads, and visual resources. These beneficial impacts result because the roadless area will not be developed for timber production.

The major adverse impacts involve anadromous and residential cold water fish populations, visual resources, and mineral and energy development. The impacts on fish populations are associated with habitat degradation anticipated in the accessible area when the roadless area remains roadless and timber harvests continue to be concentrated in the accessible area. The adverse impact on visual resources is associated with the expected reduction of natural-appearing forest landscapes in the accessible area. The adverse impact on opportunities for developing mineral and energy resources in the roadless area concerns access problems associated with the lack of an available road system.

In summary, if the reallocation alternative were adopted in place of the base alternative, specialists on the Siskiyou National Forest would anticipate major nontimber and environmental trade-offs in addition to the loss of timber harvests. Major beneficial impacts on wildlife (threatened and endangered species), dispersed recreation, and visual resources in the roadless area would be expected at the expense of major (adverse) impacts on fish populations and visual resources in the accessible area and on opportunities to develop mineral and energy resources in the roadless area.

Table 13--Summary of estimated impacts associated with withdrawing the roadless area and intensifying timber management on the remaining land on the Siskiyou National Forest

Criterion	Impacts[1]				
	Beneficial		Neutral (no change from base)	Adverse	
	Major	Minor		Minor	Major[2]
Water quality		R		A	
Water quantity			A, R		
Waterflow				A, R	
Soil stability		R		A	
Soil productivity		R		A	
Forage production (domestic)		A		R	
Fish populations (anadromous)		R			A
Fish populations (residential)		R			A
Wildlife populations (game species)		A, R			
Wildlife populations (threatened and endangered species)	R			A	
Opportunities for developed recreation		A		R	
Opportunities for dispersed recreation related to roads				A, R	
Opportunities for dispersed recreation away from roads	R			A	
Visual resources	R				A
Air quality		R		A	
Mineral and energy development		A			R

[1] R = roadless area; A = accessible area.

[2] Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple use objectives.

UMATILLA NATIONAL FOREST RESULTS

If the reallocation alternative were adopted in place of the base alternative, no roads would be built and no road-related timber harvests would occur in the roadless area. In such an event, specialists on the Umatilla National Forest anticipated two major beneficial impacts and three major adverse impacts in the roadless area as shown in table 14. No major impacts were expected in the accessible area; 3 minor beneficial impacts were expected in the roadless area and 19 neutral impacts in both areas.

The major beneficial impacts are on visual resources and opportunities for dispersed recreation away from roads. Impacts on visual resources and opportunities for dispersed recreation away from roads are associated with the proportion of the total area disturbed in the roadless area.

Table 14--Summary of estimated impacts associated with withdrawing the roadless area and intensifying timber management on the remaining land on the Umatilla National Forest

Criterion	Impacts[1]				
	Beneficial		Neutral (no change from base)	Adverse	
	Major	Minor		Minor	Major[2]
Water quality		R	A		
Water quantity			A, R		
Waterflow			A, R		
Soil stability		R	A		
Soil productivity		R	A		
Forage production (domestic)			A		R
Fish populations (anadromous)		R	A		
Fish populations (residential)		R	A		
Wildlife populations (game species)		R	A		
Wildlife populations (threatened and endangered species)		R	A		
Opportunities for developed recreation			A		R
Opportunities for dispersed recreation related to roads			A		R
Opportunities for dispersed recreation away from roads	R		A		
Visual resources	R		A		
Air quality		R	A		
Mineral and energy development			A, R		

[1] R = roadless area; A = accessible area.

[2] Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple use objectives.

The major adverse impacts involve domestic forage production, opportunities for developed recreation, and opportunities for dispersed recreation related to roads. The impacts on forage production are associated with the opportunity forgone to increase forage production in the roadless area. Likewise, the impacts on opportunities for dispersed recreation related to roads and developed recreation are linked to the opportunities to build roads and develop attractive recreation sites in the roadless area.

Useful information about trade-offs may be obtained from table 14. Three of the five major impacts concern opportunities for recreation; one was considered beneficial and two were considered adverse by the specialists. A fourth major impact involves visual resources, and the fifth major impact involves domestic forage production. In addition, all five major impacts are associated with the roadless area and are directly affected by the policy of not building roads in the roadless area. Hence, the major trade-offs associated with the Umatilla National Forest involve different forms of recreation opportunities in the roadless area. Visual resources and dispersed recreation away from roads are significantly enhanced in the roadless area at the expense (trade-off) of decreasing opportunities for developed recreation, dispersed recreation with roads, and domestic forage production. There are no major nontimber and environmental trade-offs between the roadless area and the accessible area on this Forest. All impacts related to the accessible area are neutral.

WILLAMETTE NATIONAL FOREST RESULTS

If the reallocation alternative is adopted in place of the base alternative, specialists on the Willamette National Forest anticipate one major beneficial nontimber or environmental impact and eight major adverse impacts. Six would involve the accessible area and two the roadless area. Sixteen minor beneficial impacts and seven minor adverse impacts would also be expected. All are shown in table 15.

Table 15--Summary of estimated impacts associated with withdrawing the roadless area and intensifying timber management on the remaining land on the Willamette National Forest

Criterion	Impacts[1]				
	Beneficial		Neutral (no change from base)	Adverse	
	Major	Minor		Minor	Major[2]
Water quality		R			A
Water quantity		A, R			
Waterflow		A, R			
Soil stability		R			A
Soil productivity		R		A	
Forage production (domestic)		A		R	
Fish populations (anadromous)		R			A
Fish populations (residential)		R			A
Wildlife populations (game species)				A, R	
Wildlife populations (threatened and endangered species)		R		A	
Opportunities for developed recreation		A			R
Opportunities for dispersed recreation related to roads		A		R	
Opportunities for dispersed recreation away from roads	R			A	
Visual resources		R			A
Air quality		R			A
Mineral and energy development		A			R

[1] R = roadless area; A = accessible area.

[2] Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple use objectives.

The six major adverse impacts associated with accessible area affect water quality, soil stability, anadromous and cold water residential fish populations, visual resources, and air quality. Four of these impacts are closely related to soil erosion and sediment problems. Impacts on soil stability are directly tied to erosion and mass soil movement. Water quality impacts are caused by sediment from erosion. Fish populations, both anadromous and cold water residential, are directly affected by habitat degradation which is associated with water quality, etc. Hence, these four impacts are interrelated and are expected as a result of the increased timber harvesting associated with the reallocation alternative in the accessible area.

Continued concentration of timber harvests in the presently accessible area will cause a further reduction in the supply of natural-appearing forest landscapes and thereby contribute to major adverse impacts on visual resources. Slash will accumulate with the concentrated harvests in the accessible area. Fire management policies will require burning of slash to reduce fire hazard, an action that will have an adverse effect on air quality for a short time each year.

The two major adverse impacts associated with the roadless area involve opportunities for developed recreation and development of mineral and energy resources. The adverse impact on developed recreation opportunities is a result of the forgone opportunity to develop attractive recreation sites in the roadless area when the reallocation alternative is adopted. Likewise, major adverse impacts on opportunities for mineral and energy development are anticipated mainly because of the lack of a road system in the roadless area.

In conclusion, our analysis of environmental conditions on the study Forests suggests that not only do withdrawals seem to shift the adverse and beneficial impacts of timber harvesting from roadless areas to accessible areas, they often intensify them.

Literature Cited

Gregersen, H. M.
1975. Effect of inflation on evaluation of forestry investments. J. For. 73(9):570-572

Hanzlik, E. J.
1922. Determination of the annual cut on a sustained basis for virgin American forests. J. For. 20:611-626.

Johnson, K. Norman, and H. Lynn Scheurman.
1977. Techniques for prescribing optimal timber harvest and investment under different objectives--discussion and synthesis. For. Sci. Monogr. 18, 31 p. Soc. Am. For.

Klemperer, W. David.
1976. Economic analysis applied to forestry: Does it short-change future generations? J. For. 74(9):609-611.

McKean, Roland N.
1958. Efficiency in government through systems analysis. 336 p. John Wiley, Inc., New York.

Prest, A. R., and R. Turvey.
1967. Cost-benefit analysis: A survey. *In* Survey of economic theory, Vol. 3, p. 155-207. Am. Econ. Assoc.

U.S. Laws, Statutes, etc. Public Law 95-237. [H.R. 3454].
1978. Endangered American Wilderness Act of 1978. An act to designate certain endangered public lands for preservation as wilderness, and for other purposes. Approved Feb. 24, 1978. 92 Stat. 40-46. U.S. Gov. Print. Off., Washington, D.C. [16 U.S.C. 1131-1134, 1274, 1281; 31 U.S.C. 1301; 43 U.S.C. 600f, 616.]

U.S. Water Resources Council.
1974. OBERS projections. Vol. 4, States. Washington, D.C.

Appendix A

REAL STUMPAGE PRICE (DOLLARS PER THOUSAND BOARD FEET) ASSUMPTIONS USED FOR STUDY FORESTS

Table 16--Real stumpage price assumptions for the Siskiyou National Forest

Decade	Price assumption 1[1] (constant prices)			Price assumption 2[3] (increasing prices)			Price assumption 3[4] (increasing prices)		
	Base	50 percent withdrawn[2]	100 percent withdrawn	Base	50 percent withdrawn[2]	100 percent withdrawn[2]	Base	50 percent withdrawn[2]	100 percent withdrawn[2]
				Dollars per thousand board feet					
1	173.52	176.71	183.00	227.42	231.47	239.13	227.42	254.36	298.12
2	173.52	176.71	183.00	300.67	304.73	312.41	300.67	328.89	374.68
3	173.52	176.71	183.00	347.25	351.49	359.44	347.25	380.41	433.99
4	173.52	176.71	183.00	385.62	390.05	398.29	385.62	423.72	485.08
5	173.52	176.71	183.00	420.68	425.32	433.88	420.68	464.34	534.49
6	173.52	176.71	183.00	447.62	452.36	461.10	447.62	494.14	568.79
7	173.52	176.71	183.00	447.62	452.36	461.10	447.62	494.14	568.79
8	173.52	176.71	183.00	447.62	452.36	461.10	447.62	494.14	568.79
9	173.52	176.71	183.00	447.62	452.36	461.10	447.62	494.14	568.79
10	173.52	176.71	183.00	447.62	452.36	461.10	447.62	494.14	568.79

---

[1] High bid values reported by the Forest.

[2] Percent of total roadless acreage removed from the timber management land base.

[3] RPA Timber Assessment softwood market model projection with regional Forest Service harvest unaffected by roadless withdrawals (Adams, Darius M., and Richard W. Haynes. 1978. A preliminary description of the 1980 timber assessment softwood market model. Report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.)

[4] RPA Timber Assessment softwood market model projection with regional Forest Service harvest changed by the same proportion as the proportional change between the harvest levels of the base and each alternative.

Table 17--Real stumpage price assumptions for the Umatilla National Forest

Decade	Price assumption 1[1] (constant prices)			Price assumption 2[3] (increasing prices)					Price assumption 3[4] (increasing prices)				
	Base	50 percent withdrawn,[2]	100 percent withdrawn	Base	50 percent withdrawn,[2] no reallocation	50 percent withdrawn,[2] with reallocation	100 percent withdrawn[2] no reallocation	100 percent withdrawn,[2] with reallocation	Base	50 percent withdrawn,[2] no reallocation	50 percent withdrawn,[2] with reallocation	100 percent withdrawn,[2] no reallocation	100 percent withdrawn,[2] with reallocation
							Dollars per thousand board feet						
1	60.34	62.15	63.90	78.03	80.21	80.18	82.31	82.31	78.03	82.70	82.58	87.58	87.28
2	60.34	62.15	63.90	103.02	105.20	105.19	107.31	107.30	103.02	107.22	107.43	112.02	111.99
3	60.34	62.15	63.90	108.75	110.93	110.91	113.04	113.03	108.75	113.95	113.80	119.10	119.05
4	60.34	62.15	63.90	114.65	116.83	116.80	118.93	121.93	114.65	120.31	120.15	125.93	125.88
5	60.34	62.15	63.90	120.62	122.80	122.78	124.91	124.90	120.62	126.45	126.48	132.24	132.19
6	60.34	62.15	63.90	127.44	129.62	129.60	131.72	131.72	127.44	133.19	133.03	140.91	138.86
7	60.34	62.15	63.90	127.44	129.62	129.60	131.72	131.72	127.44	133.19	133.03	140.91	138.86
8	60.34	62.15	63.90	127.44	129.62	129.60	131.72	131.72	127.44	133.19	133.03	140.91	138.86
9	60.34	62.15	63.90	127.44	129.62	129.60	131.72	131.72	127.44	133.19	133.03	140.91	138.86
10	60.34	62.15	63.90	127.44	129.62	129.60	131.72	131.72	127.44	133.19	133.03	140.91	138.86

[1] High bid values reported by the Forest.

[2] Percent of total roadless acreage removed from the timber management base.

[3] RPA Timber Assessment softwood market model projection with regional Forest Service harvest unaffected by roadless withdrawals (Adams, Darius M., and Richard W. Haynes. 1978. A preliminary description of the 1980 timber assessment softwood market model. Report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.).

[4] RPA Timber Assessment softwood market model projection with regional Forest Service harvest changed by the same proportion as the proportional change between the harvest levels of the base and each alternative.

Table 18--Real stumpage price assumptions for the Willamette National Forest

Decade	Price assumption 1[1] (constant prices)			Price assumption 2[3] (increasing prices)			Price assumption 3[4] (increasing prices)		
	Base	50 percent withdrawn[2]	100 percent withdrawn[2]	Base	50 percent withdrawn[2]	100 percent withdrawn[2]	Base	50 percent withdrawn[2]	100 percent withdrawn[2]
					Dollars per thousand board feet				
1	204.38	207.61	208.00	267.87	270.56	273.62	267.87	264.79	296.41
2	204.38	207.61	208.00	358.15	356.83	359.92	358.15	350.74	383.98
3	204.38	207.61	208.00	409.02	411.59	414.14	409.02	404.06	430.89
4	204.38	207.61	208.00	454.22	456.66	459.60	454.22	447.92	470.11
5	204.38	207.61	208.00	495.52	495.85	498.96	495.52	464.08	497.09
6	204.38	207.61	208.00	527.37	527.37	530.68	527.25	493.36	528.68
7	204.38	207.61	208.00	527.25	527.37	530.68	527.25	493.36	528.68
8	204.36	207.61	208.00	527.25	527.37	530.68	527.25	493.36	528.68
9	204.36	207.61	208.00	527.25	527.37	530.68	527.25	493.36	528.68
10	204.36	207.61	208.00	527.25	527.37	530.68	527.25	493.36	528.68

[1] High bid values reported by the Forest.

[2] Percent of total roadless acreage removed from the timber management land base.

[3] RPA Timber Assessment softwood market model projection with regional Forest Service harvest unaffected by roadless withdrawals (Adams, Darius M., and Richard W. Haynes. 1978. A preliminary description of the 1980 timber assessment softwood market model. Report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.)

[4] RPA Timber Assessment softwood market model projection with regional Forest Service harvest changed by the same proportion as the proportional change between the harvest levels of the base and each alternative.

Appendix B

Table 19--Annual real per capita income growth rate, Oregon and Washington

Year	1971	1980	1985	1990	2000	2020
			Percent			
1970	1.297	3.202	3.018	2.934	2.900	2.739
1971	--	3.416	3.142	3.021	2.956	2.768
1980	--	--	2.651	2.667	2.750	2.623
1985	--	--	--	2.682	2.783	2.619
1990	--	--	--	--	2.833	2.609
2000	--	--	--	--	--	2.497

Appendix C

DOCUMENTATION OF ROAD COSTS AND ASSUMPTIONS AND SILVICULTURAL COSTS FOR EACH STUDY FOREST

ROAD COSTS AND ASSUMPTIONS

Some of the road costs are also presented in table 2; however, a more thorough documentation of the assumptions behind road costs for each Forest follows.

Siskiyou National Forest

Table 20 shows the road miles and costs expected for development of the roadless area on the Siskiyou National Forest. The table shows that development of the half of the roadless area most likely to remain in the timber base would require substantially more roads than would development of the other roadless half. This difference reflects varying requirements for logging systems found on the two areas. Below are described the different logging systems used as well as other important assumptions behind the numbers shown in table 20.

Table 20--Road miles and costs if the roadless area remains in the timber base and roads are constructed on the roadless area of the Siskiyou National Forest

Road miles and costs	Area 2[1]	Area 3[2]	Total
Road construction (miles)	417.0	247.0	664.0
Construction, including engineering (million dollars)	34.9	21.1	56.0
1 reconstruction of the total system, including engineering (million dollars)	8.0	4.8	12.8
Maintenance of total system for 1 decade (million dollars)	5.8	3.5	9.3

[1] Area 2 contains the half of the roadless area remaining in the timber base in the partial withdrawal alternative.

[2] Area 3 contains the half of the roadless area that would be removed in the partial withdrawal alternative.

Construction

The road network needed for development of the roadless area would take 40 years to complete. In the first decade, only 20 percent of the development is expected to take place because of time needed for area reconnaissance and preparation of development plans; 30 percent of the development is expected to take place in each of the second and third decades; and the final 20 percent in the fourth decade. The density of roads in a given area will vary by the log yarding system used. Total construction and reconstruction costs take into account that part of the road system will be of all-weather standard and part will be of seasonal standard.

A necessary component of developing total construction costs were the road miles to square mile ratios (existing road areas average about 2.6 miles/square mile). These ratios were applied in each roadless area to calculate miles of road needed for development.

Logging system	All-weather roads	Seasonal roads	Total
	(Road miles/square mile)		
Highlead and short span skyline	2.0	2.0	4.0
Long span skyline	1.3	.7	2.0
Helicopter	.6	.4	1.0

If the total roadless area were removed from the timber harvest base, it might be necessary to build additional roads in the currently accessible area to connect some ends of the existing road system for administrative purposes; 35 miles of additional roads may be needed to accomplish these ends.

If half the roadless area is removed from the timber harvest base, about 25 miles of additional roads may be needed.

Reconstruction

It is assumed that each mile of road is reconstructed within 20 years after original construction. It is further assumed that road standards will remain the same when reconstruction takes place. Average reconstruction costs for all standards are assumed to be approximately $19,300 per mile, including engineering costs (at 1978 prices). Applying this average to one reconstruction of the entire road system necessary to develop the roadless area results in a total reconstruction cost of $12,800,000.

If the roadless area is not developed, savings will be offset somewhat by reconstruction of the 25 and 35 additional road miles required in the currently accessible area if 50 percent and 100 percent, respectively, of the roadless area is removed from the timber base.

Maintenance

In the first four decades, each mile of road constructed in the development of the roadless area will require an average of 20 years of maintenance; roads built in the 1st year will be maintained for 40 years, and roads built in the last year will be maintained for 1 year.

If the total roadless area is removed from the timber harvest base, maintenance impacts on the area with roads include the 35 additional miles of road.

If only half the roadless area is removed from the timber base, maintenance impacts on the area with roads include maintenance of the 25 additional miles of road built.

Umatilla National Forest

Table 21 shows road miles and costs expected for development of the roadless area on the Umatilla National Forest. A total of 657 miles of new road construction would be required to develop the roadless area; of this, 360 miles would be built in that part of the roadless area considered most likely to remain in the base if 50 percent of the roadless area were withdrawn, and 297 miles would be built in that part of the roadless area considered most likely to be withdrawn from the base.

Table 21--Road miles and costs if the roadless area remains in the timber base and roads are constructed on the roadless area of the Umatilla National Forest

Road miles and costs	Area 2[1]	Area 3[2]	Total
Road construction (miles)	360.0	297.0	657.0
Construction, including engineering (million dollars)	18.8	16.9	35.7
1 reconstruction of the total system, including engineering (million dollars)	2.5	2.2	4.7
Maintenance of total system for 1 decade (million dollars)	3.2	2.7	5.9

[1] Area 2 contains the half of the roadless area remaining in the timber base in the partial withdrawal alternative.

[2] Area 3 contains the half of the roadless area that would be removed in the partial withdrawal alternative.

Construction

The road network needed for development of the roadless area is expected to be built in the next 40 years. Costs of construction vary widely by road standards and land characteristics, but for the purposes of this study, an average cost of $54,400 per mile is used for the entire road network planned for the roadless area. This average cost includes engineering costs as well as the actual construction costs.

The capital investment schedule for road construction and the cost per decade follow:

Decade	Roads constructed	Construction cost
	(Percent)	(Dollars)
1	40	14,298,000
2	25	8,936,000
3	20	7,149,000
4	15	5,362,000
	100	35,745,000

Table 21 shows how the total cost is divided between the two roadless area halves used in the partial withdrawal alternative.

Reconstruction

Road reconstruction was assumed to take place in the 20th year after initial construction. Reconstruction costs of nonpaved roads were assumed to 10 percent of the initial construction cost.

Average reconstruction costs for all standards of roads, paved as well as nonpaved, was $7,209 per mile, including engineering cost. Applying this average to one reconstruction of the entire road system needed to develop the roadless area results in a total reconstruction cost of $4,736,000. Costs per decade for the reconstruction are:

Decade	Cost (Dollars)
1	0
2	0
3	1,894,000
4	1,184,000
5+	1,658,000

Maintenance

Maintenance costs are annual costs based on hauling timber. Once the road system is in place, it will cost $591,300 per year to maintain it. Table 21 shows the decadal cost of maintenance. Costs for the first four decades, when the road system is not entirely in place, are:

Decade	Cost (Dollars)
1	1,306,000
2	3,192,000
3	4,513,000
4	5,537,000

Willamette National Forest

Table 22 shows road miles and costs expected for development of the roadless area on the Willamette National Forest. A total of 488 miles of road construction will be required to develop the roadless area access system. If only half the roadless area is developed, 277 miles of new road construction will be necessary.

Construction

The road network for the roadless area is expected to be developed in the next 40 years. Costs of construction vary by road standards, topography, soil conditions, and other factors. The average cost per mile for the total 488-mile system is $116,434.

Table 22--Road miles and costs if the roadless area remains in the timber base and roads are constructed on the roadless area of the Willamette National Forest

Road miles and costs	Area 2[1]	Area 3[2]	Total
Road construction (miles)	277.0	211.0	488.0
Construction, including engineering (million dollars)	32.4	24.4	56.8
1 reconstruction of the total system, including engineering (million dollars)	7.8	5.9	13.7
Maintenance of total system for 1 decade (million dollars)	1.7	1.3	3.0

[1] Area 2 contains the half of the roadless area remaining in the timber base in the partial withdrawal alternative.

[2] Area 3 contains the half of the roadless area that would be removed in the partial withdrawal alternative.

The capital investment schedule for road construction and the cost per decade for total development follow:

Decade	Roads constructed	Cost
	(Percent)	(Dollars)
1	32	20,410,000
2	35	18,810,000
3	21	11,220,000
4	12	6,380,000
		56,820,000

Table 22 shows how the $56,820,000 construction costs are divided between the roadless area halves.

If roads are built in the roadless area, this will also produce changes in the rate of road construction and thus in the timing of costs in already accessible area. Analysis of these changes showed that although the timing would change, costs over the four decade period would not change significantly if the roadless area remains undeveloped.

Reconstruction

Road reconstruction was assumed to progress at an annual rate of 5 percent of the total miles of roads. These costs are zero in the first decade, then gradually increase until the entire road system is built, at which time they level off. Reconstruction costs were assumed to be $28,000 per mile. Reconstruction costs of roads constructed in the roadless area for the first four decades totaled $10,100,000. Costs per decade for the first reconstruction are:

Decade	Cost
	(Dollars)
1	0
2	1,209,000
3	3,514,000
4	5,377,000
5+	3,564,000

The costs of reconstruction in the roadless area is partly offset by $4,770,000 saved over four decades by a lower rate of reconstruction in the presently accessible area.

Maintenance

Road maintenance is assumed to take place annually over the entire road system. The total average annual maintenance cost was estimated at $600 per mile and was based on the sum of nontraffic generated maintenance costs of $150 per mile and traffic generated maintenance costs of $450 per mile. For the roadless area, the total annual maintenance charge would be the accumulated miles of road completed times $600. If the road system is developed for the total roadless area, it will cost $3 million per decade to maintain.

Total costs for four decades for nontraffic generated maintenance in the roadless area will be $1,763,000. This will be offset by savings of $602,000 in the accessible area. The four-decade costs for traffic generated maintenance are the difference between maintenance costs for the roadless area and for the accessible area--$2,668,000.

Logging and hauling cost differences between the roadless area and the currently accessible area need to be considered in addition to road costs. Differences in types of harvesting systems needed on the two areas indicate that stump to truck costs will be greater on the roadless area. Hauling costs will also be greater on the roadless area because of the greater distance from mills. These cost differences are reflected in the stumpage price differentials between the roadless area and the currently accessible area (table 2).

Table 23--Silvicultural costs[1] for the study Forests

Item	National Forest		
	Siskiyou	Umatilla	Willamette
Reforestation cost per nonstocked acre (dollars/acre)	200.00	160.00	312.00
Reforestation cost per cutover acre (dollars/acre)	170.00	160.00	204.00
Restocking cost per acre, brushfield conversion (dollars/acre)	526.00	--	--
Precommercial thinning (dollars/acre)	127.00	75.00	87.00
Release (dollars/acre)	60.00	12.50	12.50
Timber sale cost (dollars/thousand cubic feet)	31.10	53.75	16.82

[1] Costs are average; all acres are assumed to be in the base.

Appendix D

SUMMARY AND DETAILED FINANCIAL CONSEQUENCES FOR STUDY FORESTS WHEN PROPORTIONAL CHANGES IN HARVEST ON OTHER NATIONAL FORESTS ARE ASSUMED

Table 24--Change in present net worth and payments to counties between the base programed harvest and the reallocation alternatives[1]

Forest and alternative	Change in PNW[2]	Change in payments to counties[3]
	Million dollars	Million dollars per year
Siskiyou National Forest:		
50 percent of roadless area withdrawn	-33.1	-0.7
100 percent of roadless area withdrawn	-129.2	-2.7
Umatilla National Forest:		
50 percent of roadless area withdrawn	6.7	-.2
100 percent of roadless area withdrawn	12.7	-.4
Willamette National Forest:		
50 percent of roadless area withdrawn	74.1	.9
100 percent of roadless area withdrawn	-39.4	-1.0

[1] Trends in real prices expected with proportional changes in harvests on other National Forests and expected trends in real costs were used.

[2] Present net worth for 10 decades at 5-percent interest rate.

[3] Payments to counties are averages for the first 4 decades.

Table 25--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Siskiyou National Forest[1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	44.9	-5.8	-14.9
2. Gross revenue (million dollars per year)	67.9	-2.8	-10.6
3. Cost of roads (million dollars per year)	NA	-.7	-2.1
4. Cost of cultural treatments (million dollars per year)	NA	.2	-.7
5. Cost of selling timber (million dollars per year)	NA	-.4	-.9
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	-1.9	-6.9
7. Payments to counties (million dollars per year)	17.0	-.7	-2.7
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	-33.1	-129.2
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	-13.8	-54.4

NA = not available.

[1] Trends in real stumpage prices expected with proportional changes in harvest on other Douglas-fir region National Forests in the Pacific Northwest and expected trends in real costs were used.

Table 26--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Umatilla National Forest[1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	26.2	-2.2	-4.5
2. Gross revenue (million dollars per year)	17.1	-.7	-8.2
3. Cost of roads (million dollars per year)	NA	-.6	-1.3
4. Cost of cultural treatments (million dollars per year)	NA	-.1	-.3
5. Cost of selling timber (million dollars per year)	NA	-.3	-.5
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	.3	.6
7. Payments to counties (million dollars per year)	4.3	-.2	-.4
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	6.7	12.7
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	4.2	8.2

NA = not available.

[1] Trends in real stumpage prices expected with proportional changes in harvest on other ponderosa pine region National Forests in the Pacific Northwest and expected trends in real costs were used.

Table 27--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Willamette National Forest[1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	115.4	3.2	-12.5
2. Gross revenue (million dollars per year)	232.2	3.6	-4.1
3. Cost of roads (million dollars per year)	NA	-1.0	-1.7
4. Cost of cultural treatments (million dollars per year)	NA	.7	-.1
5. Cost of selling timber (million dollars per year)	NA	.3	-.1
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	3.6	-2.2
7. Payments to counties (million dollars per year)	58.1	.9	-1.0
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	74.1	-39.4
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	35.5	-19.4

NA = not available.

[1] Trends in real stumpage prices expected with proportional changes in harvest on other Douglas-fir region National Forests in the Pacific Northwest and expected trends in real costs were used.

Appendix E

SUMMARY AND DETAILED FINANCIAL CONSEQUENCES FOR STUDY FORESTS WHEN CONSTANT REAL PRICES AND CONSTANT REAL COSTS ARE ASSUMED

Table 28--Change in present net worth and payments to counties between the base programed harvest and the reallocation alternatives[1]

Forest and alternative	Change in PNW[2]	Change in payments to counties[3]
	Million dollars	Million dollars per year
Siskiyou National Forest:		
50 percent of roadless area withdrawn	-69.5	-1.0
100 percent of roadless area withdrawn	-164.7	-2.7
Umatilla National Forest:		
50 percent of roadless area withdrawn	5.4	-.1
100 percent of roadless area withdrawn	11.0	-.3
Willamette National Forest:		
50 percent of roadless area withdrawn	122.0	1.4
100 percent of roadless area withdrawn	-155.8	-2.2

[1] Constant real prices and constant real costs were used.

[2] Present net worth for 10 decades with 5-percent interest rate.

[3] Payments to counties are averages for the first 4 decades.

Table 29--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Siskiyou National Forest[1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	44.9	-5.8	-14.9
2. Gross revenue (million dollars per year)	37.4	-4.2	-11.0
3. Cost of roads (million dollars per year)	NA	-.7	-2.1
4. Cost of cultural treatments (million dollars per year)	NA	.1	-.4
5. Cost of selling timber (million dollars per year)	NA	-.2	-.5
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	-3.4	-8.0
7. Payments to counties (million dollars per year)	9.3	-1.0	-2.7
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	-69.5	-164.7
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	-36.4	-86.0

NA = not available.

[1] Constant real stumpage prices and real costs were used.

Table 30--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Umatilla National Forest [1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	26.2	-2.2	-4.5
2. Gross revenue (million dollars per year)	10.2	-.6	-1.3
3. Cost of roads (million dollars per year)	NA	-.6	-1.3
4. Cost of cultural treatments (million dollars per year)	NA	-.1	-.2
5. Cost of selling timber (million dollars per year)	NA	-.2	-.3
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	.3	.5
7. Payments to counties (million dollars per year)	2.6	-.1	-.3
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	5.4	11.0
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	3.2	6.7

NA = not available.

[1] Constant real stumpage prices and real costs were used.

Table 31--Four-decade average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management, Willamette National Forest[1]

Item	Base programed harvest	Change when 50 percent of the roadless area is withdrawn	Change when 100 percent of the roadless area is withdrawn
1. Harvest (million cubic feet per year)	115.4	3.2	-12.5
2. Gross revenue (million dollars per year)	127.8	5.6	-8.9
3. Cost of roads (million dollars per year)	NA	-1.0	-1.7
4. Cost of cultural treatments (million dollars per year)	NA	.6	-.1
5. Cost of selling timber (million dollars per year)	NA	.2	-.1
6. Net revenue--item 2 minus items 3, 4, and 5 (million dollars per year)	NA	6.8	-7.0
7. Payments to counties (million dollars per year)	32.0	1.4	-2.2
8. Present net worth for 10 decades at 5 percent (million dollars)	NA	122.0	-155.8
9. Present net worth for 10 decades at 10 percent (million dollars)	NA	61.1	-93.9

NA = not available.

[1] Constant real stumpage prices and real costs were used.

Appendix F

EMPLOYMENT CONSEQUENCES FOR THE SISKIYOU, UMATILLA, AND WILLAMETTE NATIONAL FORESTS, JULY 28, 1978

Siskiyou National Forest[1]

Harvest alternative	Deviations from actual employment	Deviations from opportunities to increase employment	Total
50 percent of roadless area withdrawn from timber base--no reallocation of funds	0	-780	-780
50 percent of roadless area withdrawn from timber base--reallocation of funds	0	-780	-780
100 percent of roadless area withdrawn from timber base--no reallocation of funds	-944	-1,066	-2,010
100 percent of roadless area withdrawn from timber base--reallocation of funds	-944	-1,066	-2,010

[1] Base programed harvest level of employment is 6,067 attributable to a base harvest level of 215.466 million board feet per year; actual employment level is 5,001 attributable to a recent harvest (average annual chargeable harvest for 1968-77) of 177.6 million board feet per year.

Umatilla National Forest[1]

Harvest alternative	Deviations from actual employment	Deviations from opportunities to increase employment	Total
0 percent of roadless area withdrawn from timber base--no reallocation of funds	-4	-257	-261
0 percent of roadless area withdrawn from timber base--reallocation of funds	0	-251	-251
00 percent of roadless area withdrawn from timber base--no reallocation of funds	-268	-257	-525
00 percent of roadless area withdrawn from timber base--reallocation of funds	-264	-257	-521

---

[1] Base programed harvest level of employment is 3,016 attributable to a base arvest level of 169.229 million board feet per year; actual employment level is ,758 attributable to a recent harvest (average annual chargeable harvest for 968-77) of 154.8 million board feet per year.

Willamette National Forest[1]

Harvest alternative	Deviations from actual employment	Deviations from opportunities to increase employment	Total
0 percent of roadless area withdrawn from timber base--no real allocation of funds	0	-834	-834
0 percent of roadless area withdrawn from timber base--reallocation of funds	0	502	502
00 percent of roadless area withdrawn from timber base--no reallocation of funds	-1,058	-921	-1,979
00 percent of roadless area withdrawn from timber base--reallocation of funds	-1,058	-921	-1,979

---

[1] Base programed harvest level of employment is 18,215 attributable to a base arvest level of 625.439 million board feet per year; actual employment level is ,732 attributable to a recent harvest (average annual chargeable harvest for 968-77) of 574.52 million board feet per year.

Appendix G

ROADLESS AREAS IN THIS STUDY, BY FOREST

ROADLESS AREAS, SISKIYOU NATIONAL FOREST

The 50-percent roadless area alternative contained some roadless areas that subsequently came under the Endangered American Wilderness Act (U.S. Laws, Statutes, etc. Public Law 95-237, 1978) and parts of other roadless areas that remain in RARE II. A map showing these areas is on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

NAMES OF ROADLESS AREAS, UMATILLA NATIONAL FOREST

Hellhole
Owsley
Horseshoe Ridge
Lookingglass
Mt. Emily
Big Sinks
South Fork
Tower

Jumpoff Joe
Battle Creek
Kelly
Texas Butte
Walla Walla River[1]
North Fork Umatilla[1]
Grande Ronde[1]
North Fork John Day[1]
Greenhorn Mountain[1]

---

[1] In the 50-percent alternative, these areas are withdrawn from the imber base and remain roadless.

NAMES OF ROADLESS AREAS, WILLAMETTE NATIONAL FOREST

Little North Santiam[1]
Elkhorn
Middle Santiam
Pyramids
Moose Lake
Rooster Rock
Echo Mountain[1]
Gordon Meadows
Jumpoff Joe

Browder[1]
Smith Reservoir
McLennen Mountain
Walker Creek[1]
French Pete[1]
Rebel Creek[1]
Chucksney Mountain[1]
Maiden Peak[2]
Packard Creek
Timpanogas[1]

---

[1] In the 50-percent alternative these areas are withdrawn from the imber base and remain roadless.

[2] Only the Waldo Lake Recreation Area portion of the Maiden Peak oadless area remains roadless (46,077 acres) in the 50-percent lternative.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
809 N.E. 6th Ave.
Portland, Oregon 97232

Randall, Robert M., Roger D. Fight, Kent P. Connaughton, Robert W. Sassaman, and K. Norman Johnson.
1979. Roadless area-intensive management trade-offs on Pacific Northwest National Forests. USDA For. Serv. Res. Pap. PNW-258, 69 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This study tested the hypothesis that timber harvest levels could be maintained on selected Pacific Northwest National Forests without harvesting from roadless areas, if resources saved by not developing the roadless areas were used for more intensive timber management on the remaining land. The study also examined the employment, financial, environmental, and multiple use implications if such a course of action were followed.

KEYWORDS: Wilderness management, land use, policy (forest), intensive management, economic evaluation.

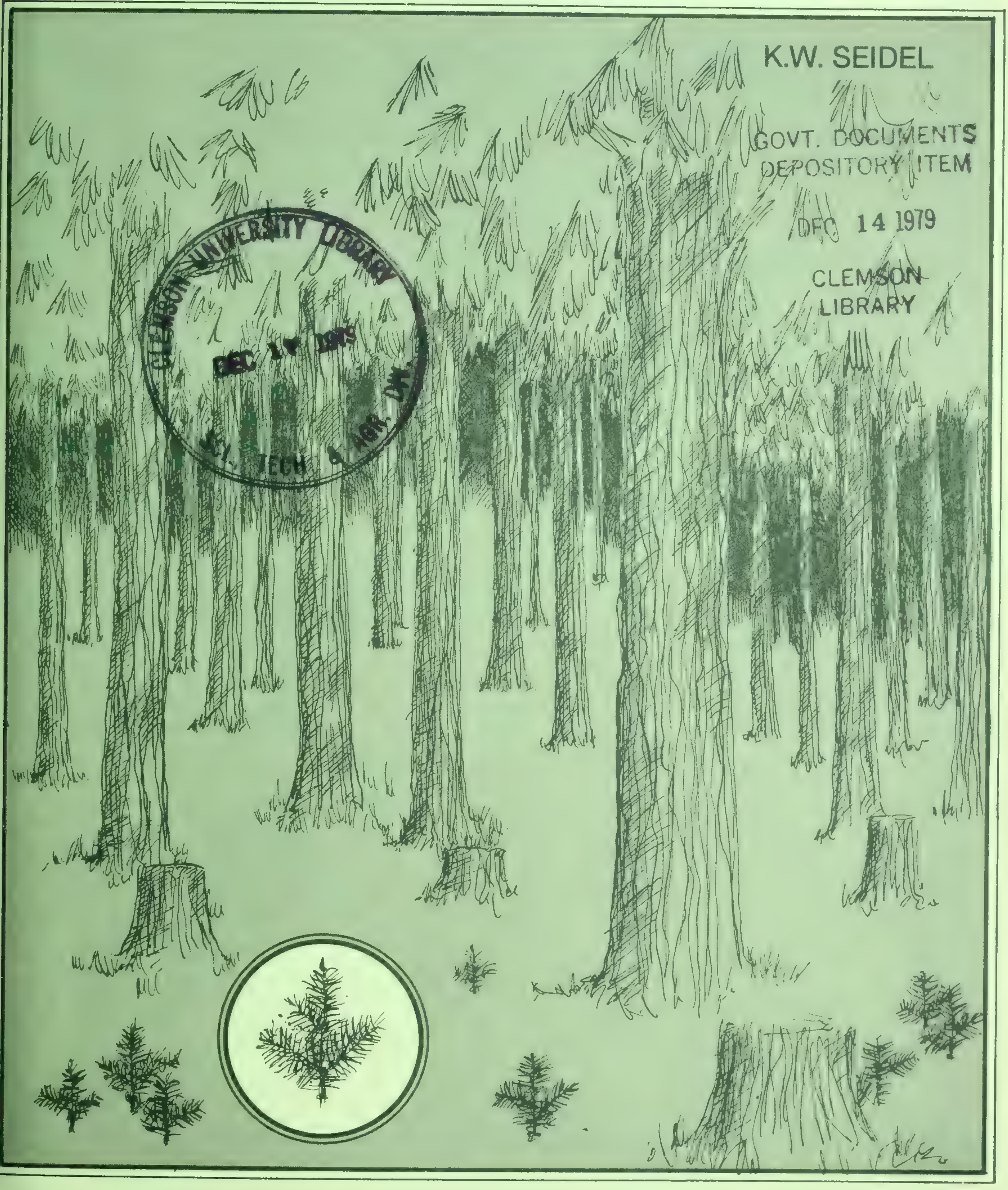
GPO 989-174

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Research Paper PNW — 259
JULY 1979

NATURAL REGENERATION AFTER SHELTERWOOD CUTTING IN A GRAND FIR-SHASTA RED FIR STAND IN CENTRAL OREGON



K.W. SEIDEL

GOVT. DOCUMENTS
DEPOSITORY ITEM
DEC 14 1979
CLEMSON
LIBRARY

CLEMSON UNIVERSITY LIBRARY
DEC 17 1985
SCI. TECH & AGR. DIV.

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.304 8 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.229 6 square meter/hectare
1 tree/acre = 2.47 trees/hectare

NATURAL REGENERATION AFTER SHELTERWOOD CUTTING IN A GRAND FIR-SHASTA RED FIR STAND IN CENTRAL OREGON

Reference Abstract

Seidel, K. W.
1979. Natural regeneration after shelterwood cutting in a grand fir-Shasta red fir stand in central Oregon. USDA For. Serv. Res. Pap. PNW-259, 23 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Natural regeneration was good to excellent 5 years after shelterwood cutting to three overstory densities (50, 90, and 130 ft^2 per acre) in a mixed conifer stand on the Deschutes National Forest in central Oregon. Seedling density ranged from about 1,875 per acre on the low density plots to 4,627 per acre on the high density plots and consisted of about 85 percent true fir (grand and Shasta red) and 15 percent ponderosa, lodgepole, and western white pine. Mineral soil was the most favorable seed bed for germination and seedling survival, but many true fir seedlings did become established in light to medium litter layers. A residual overstory of about 50 ft^2 of basal area per acre appears adequate to provide natural regeneration within a 5-year period.

KEYWORDS: Shelterwood cutting method, regeneration (natural), grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica* var. *shastensis*, Oregon (central).

Research Summary
Research Paper PNW-259
1979

In 1973, a study was begun on the Deschutes National Forest to obtain information about natural regeneration using the shelterwood system in an old-growth mixed conifer stand. The aim was to determine the effects of several residual overstory density levels and several slash treatments on establishment and growth of the regeneration. Changes in seedling numbers and stocking, seed production, seed bed condition, and understory vegetation for a 5-year period after the seed cut were evaluated.

The
fores
can b
vicul
uneve
1960'
used
Natic
natur
cuts
true
(Grat
natur
(Frar

Rec
parti
micro
clear
favor
estat
begar
the
clea

Al
now
Oreg
fore
gard
estal
sity
beds
fore
obta
rege
stan
tral
deta
tion
grow
unde
5-ye
two-

INTRODUCTION

The upper slope mixed conifer forests of the Oregon Cascade Range can be managed with a number of silvicultural systems--both even- and uneven-aged. In the 1950's and early 1960's, primarily clearcutting was used to harvest true fir stands on National Forest lands. Success of natural regeneration on these clearcuts has been mixed; in some cases true fir stocking has been adequate (Gratkowski 1958), but in others natural reproduction has been lacking (Franklin 1965).

Recognizing that some type of partial cutting might moderate the microclimatic extremes occurring in clearcuts and thus provide a more favorable environment for seedling establishment, the Forest Service began using the shelterwood system in the 1960's as an alternative to clearcutting in the upper slope types.

Although the shelterwood system is now used extensively in east-side Oregon and Washington mixed conifer forests, information is lacking regarding the relationship of seedling establishment to residual stand density, or the effect of various seed beds on seedling survival. Therefore, in 1973, I began a study to obtain some insights into the natural regeneration response of a true fir stand in the eastern Cascades of central Oregon. This paper reports detailed information on seed production, seedling establishment and growth, seed bed conditions, and understory vegetation response for a 5-year period after the seed cut in a two-stage shelterwood system.

OBJECTIVES

The primary objective of this study was to determine the effect of several intensities of shelterwood cuttings and several types of slash treatments in a mature true fir stand on the establishment, survival, and height growth of the natural regeneration. A secondary objective was to determine soil and seedling moisture stress and surface temperature conditions existing during the first growing season and to observe understory vegetation response.

STUDY AREA

The study site is located in a single 50-acre old-growth mixed conifer stand on Royce Mountain on the Crescent Ranger District of the Deschutes National Forest about 10 miles northwest of Cresent, Oregon on a south-facing 10-percent slope at an elevation of about 5,600 feet.[1/] The soil is a well drained Regosol (Vitrandept) developed in dacite pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. It has an A1, AC, C1, C2 pumic horizon about 3 to 4 feet deep over the buried soil which is a sandy loam Paleosol developed in older volcanic ash.

Before study installation, basal area ranged from 150 to 300 ft^2 per

---

[1/] Metric equivalents are on inside front cover.

acre and most trees were over 150 years old. Gross volume (Scribner) averaged about 36,000 board feet per acre. There were about 74 trees per acre, of which 75 percent were grand fir (*Abies grandis* (Dougl.) Lindl.),[2] 11 percent Shasta red fir (*A. magnifica* var. *shastensis* Lemm.), 8 percent ponderosa pine (*Pinus ponderosa* Laws), and 2 percent each of lodgepole pine (*Pinus contorta* Dougl.), western white pine (*Pinus monticola* Dougl. ex D. Don), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Average diameter was about 20 inches for grand fir, 28 inches for red fir, and 30 inches for ponderosa pine. Site index of grand fir based on Schumacher's (1926) curves indicates a height of 53 feet at age 50.

The study area is located in a mixed conifer/manzanita plant community (Volland 1976). Ground vegetation consists primarily of pinemat manzanita (*Arctostaphylos nevadensis*), kinnikinnick (*A. uva-ursi*), and prince's pine (*Chimaphilla umbellata*). Small amounts of other genera such as *Stipa, Carex,* and *Epilobium* are also present. The litter and duff layer of the forest floor before logging generally was present throughout the study area in a compact mat about 1 to 2 inches deep with less than 5 percent mineral soil exposed.

METHODS

The study consists of a completely randomized split-plot design replicated two times for a total of six 1-acre whole plots. Each whole plot was divided into four 1/4-acre subplots. Residual overstory density levels were tested on the whole plots and slash treatments were tested on the subplots. The overstory density factor consists of three levels and was based on leaving 25, 45, and 65 percent of the average basal area of all plots before cutting. This resulted in residual densities of 50, 90, and 130 ft^2 of basal area per acre or an average of 16, 31, and 58 trees per acre (fig. 1). The slash factor consists of four treatments: none, lop and scatter, expose mineral soil by removing all litter and slash with bulldozer, and crush slash by running bulldozer over subplot.

Each 1 acre, whole plot was surrounded by an isolation strip 200 feet in width to minimize seedfall from adjacent plots. Overstory density in the isolation strip was marked to the same basal area level as the plot itself. Leave trees (fully crowned dominants and codominants) were marked on all plots and isolation strips. After logging was completed in the fall of 1973, the four slash treatments were applied to subplots. Varying amounts of advance reproduction were present when plots were established, but nearly all of it was destroyed in the logging and slash disposal operations. In the summer of 1974, a grid of 25 permanent circular 1-milacre plots was

---

[2] Grand fir and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) form a continuously varying biological complex in eastern Oregon. This complex is referred to as grand fir in this paper.

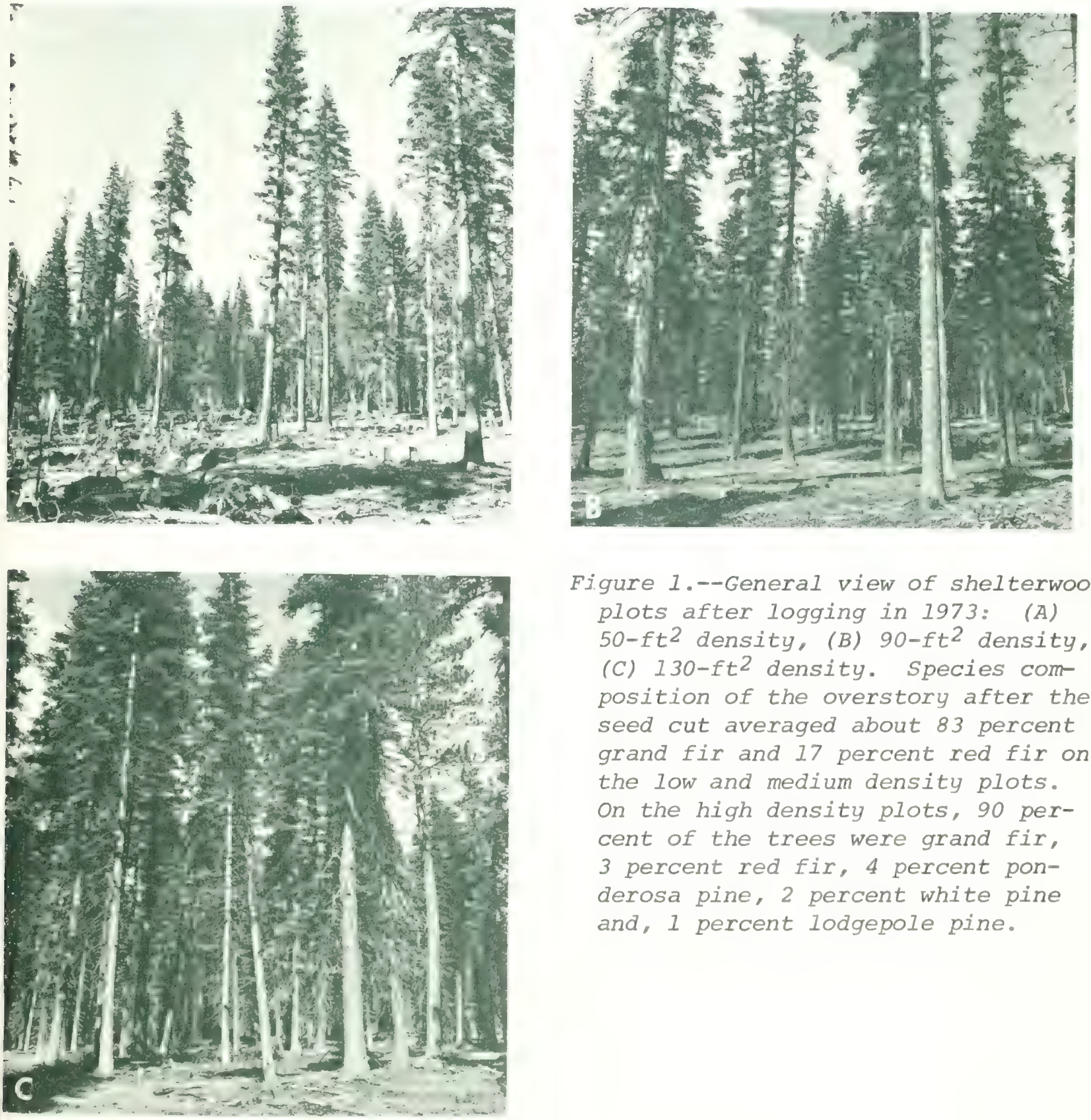


Figure 1.--General view of shelterwood plots after logging in 1973: (A) 50-ft^2 density, (B) 90-ft^2 density, (C) 130-ft^2 density. Species composition of the overstory after the seed cut averaged about 83 percent grand fir and 17 percent red fir on the low and medium density plots. On the high density plots, 90 percent of the trees were grand fir, 3 percent red fir, 4 percent ponderosa pine, 2 percent white pine and, 1 percent lodgepole pine.

established on each 1/4-acre subplot. Milacre plots were systematically spaced at 20-foot intervals on five parallel lines 20 feet apart containing five milacres each. Annually for 5 years beginning in the fall of 1974, the total number of seedlings of each species was counted and recorded on each milacre. Seedlings were identified by year of establishment by placing a color coded wire pin by each seedling so that annual mortality of each years seedlings could be determined. Total height of the tallest seedling of each species was also measured annually on each milacre. The following environmental factors associated with each milacre were measured or observed and recorded at the time of seedling counts: aspect, slope, seed bed condition (mineral soil, litter, slash), and understory vegetation (forbs, shrubs, grass).

Seed bed classes as proposed by Gordon (1970) were used. They are:

Mineral soil: Bare soil or soil with very minor amounts of organic material on the surface or in mixture.

Litter:

Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.

Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.

Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generally in a compact mat, little or no mineral soil visible.

Slash:

Light: Small pieces of slash covering less than 30 percent of surface.

Medium: Any size slash covering 30 to 60 percent of surface.

Heavy: Any size slash covering over 60 percent of surface.

Mineral soil was an exclusive surface type; litter and slash were not exclusive. In other words, if a quadrat was classified as mineral soil, no litter and slash combinations were allowed. Thus a given quadrat could receive a classification such as mineral soil, or medium litter, or light litter and heavy slash.

The understory vegetation classes used were:

Light: covering 5-30 percent of milacre.

Medium: covering 30-60 percent of milacre.

Heavy: covering more than 60 percent of milacre.

Seedfall on each whole plot was sampled annually with twenty 2.83-ft^2 traps located on a grid consisting of 5 rows; 4 traps to a row. Seeds were collected annually in June and were cut to determine numbers of sound and empty seed by species.

Overstory basal area density at each milacre was measured with a 10-factor prism in 1974.

Cones on 15 grand fir and 15 red fir trees within the study area were counted annually from 1974 through 1978. Cones were counted with binoculars from the same point each year and only "seen" cones were reported; no factor was used to adjust for "unseen cones."

During the summer of 1975, when numerous newly germinated seedlings were present on the study area, soil moisture content was measured gravimetrically at depths of 3, 6, 12, and 18 inches in two of the slash treatments (bulldozed and none) at each of the three density levels. Soil moisture tension (soil matric potential) was estimated from the soil moisture depletion curve for each depth. Moisture stress (xylem pressure potential) of true fir seedlings was measured periodically during their first growing season with a portable pressure bomb as described by Waring and Cleary (1967). All measurements were taken from 1100 to 1300 hours P.S.T. on seedlings in full sunlight to determine peak stresses.

Surface temperatures of soil and litter were measured in the same subplots used for soil moisture measurements with Tempils[3] having melting points of 125°, 138°, 150°, and 163° F (51.7°, 58.9°, 65.6°, and 72.8° C).

Analyses of variance were used to test significance of treatment effects.

RESULTS AND DISCUSSION

Seed Production and Dispersal

True fir cone production showed the typical pattern of a year of heavy cone yields followed by several years of light production found by Franklin et al. (1974). Heavy cone crops of both grand fir and Shasta red fir were produced in 1974 and 1978 with light to medium crops during the other years (fig. 2). In 1974, grand fir produced almost twice as many cones per tree, on the average, than red fir; but during the other years red fir cone yield was greater than grand fir.

---

[3] Tempils are small, aspirin-sized tablets, with various melting points. Manufactured by Tempil Corporation, 132 W. 22nd S., New York, N.Y. Trade name of product is mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

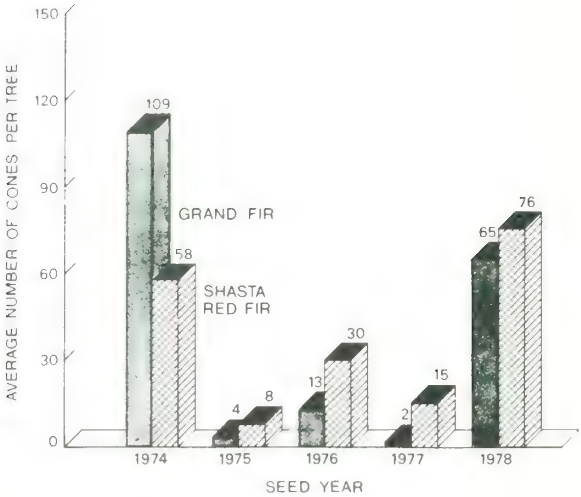


Figure 2.--Average number of cones per tree by species and year. Based on binocular counts of visible cones only. No blow-up factor used to adjust for unseen cones.

As a result of the heavy cone production in the fall of 1974, sound seed falling on the plots during that year was estimated to range from 70,783 per acre on the low density plots (50-ft^2) to 220,474 per acre on the high density plots (130-ft^2) (table 1). This was 23 to 28 percent of the total seed catch for that year. Grand fir seed was the major species found in the traps; comprising about 60 to 80 percent of the total seedfall. Ponderosa and lodgepole pine seed were the smallest component of the total seedfall, but because of their greater soundness sometimes accounted for the bulk of the sound seed on the plots. For example, in 1976, on the high density plots, only 18 percent of the total seed were pine but 79 percent of the sound seed were pine because of the large difference in soundness (54 percent for pine vs. 3.2 percent for fir) (table 1).

The pattern of cone and seed production found in this study together with the cyclical pattern of heavy cone crops at 3- to 4-year intervals reported by Franklin et al. (1974) suggests that there is a good chance of a heavy true fir cone crop occurring at least once in any 5-year period. Obviously a "bumper" crop cannot be expected the first year after the seed cut. In this study no seed was produced in 1973 immediately after logging and seed bed treatments. As long as the seed bed is not occupied at once by aggressive competing vegetation, however, a delay of several years in obtaining a heavy cone crop is not serious.

Seedling Establishment, Survival, and Height Growth

In the fall of 1975, an abundance of 1-year-old seedlings was found on all plots as a result of the heavy cone crop in 1974. On the low (50 ft^2) and medium (90 ft^2) density plots there were about 3,000 seedlings per acre and on the high density (130 ft^2) plots over 7,000 seedlings per acre (fig. 3A and appendix table 9). Seedlings were well distributed over the plots with stocking of the milacre quadrats ranging from 69 to

Table 1--Average number of sound and total seed per acre, with standard errors, falling on plots during the period 1974-1978 by species and density level

Density level and species	Seed Year[1/]											
	1974			1975			1976			1977		
	Sound	Total	Percent sound	Sound	Total	Percent sound	Sound	Total	Percent sound	Sound	Total	Percent sound
	- - - - Number - - - -			- - - - Number - - - -			- - - - Number - - - -			- - - - Number - - - -		
50 ft^2												
Grand fir	60,718± 6,600	262,397±13,120	23.1	810± 583	17,823±3,386	4.5	3,240±1,175	62,379±6,858	5.2	9,316±2,056	27,948±5,684	33.3
Shasta red fir	4,233± 1,395	32,200± 4,830	13.1	0 --	3,504±1,296	0	2,025± 689	13,772±2,892	14.7	4,861±1,434	12,152±2,912	40.0
Ponderosa and Lodgepole pine	5,832± 1,632	8,162± 1,795	71.5	385± 385	5,509±1,542	7.0	13,367±2,807	20,658±3,511	64.7	3,240±1,184	5,265±1,454	61.5
Total	70,783± 6,370	302,759±15,138	23.4	1,195± 823	26,836±5,367	4.5	18,632±3,913	96,809±8,713	19.2	17,417±3,603	45,365±8,259	38.4
90 ft^2												
Grand fir	79,270± 7,134	362,872±16,329	21.8	1,540± 976	30,400±5,472	5.1	7,697±1,847	65,033±6,742	11.8	10,176±2,256	33,563±4,862	30.3
Shasta red fir	7,696± 1,847	51,564± 5,672	14.9	0 --	1,539± 875	0	1,540± 862	10,006±2,853	15.4	3,977±1,609	12,528±2,587	31.7
Ponderosa and lodgepole pine	3,463± 1,281	6,542± 1,766	52.9	770± 623	6,927±1,662	11.1	8,081±2,020	19,626±3,612	41.2	428± 428	2,864± 981	14.9
Total	90,429± 8,138	420,978±18,944	21.5	2,310± 785	38,866±4,275	5.9	17,318±3,403	94,665±8,614	18.3	14,581±3,098	48,955±6,167	29.8
130 ft^2												
Grand fir	211,785±10,589	736,640±29,465	28.8	1,154± 750	24,912±5,481	4.6	2,886± 972	93,989±8,512	3.1	14,526±2,727	39,154±4,182	37.1
Shasta red fir	5,550± 1,554	30,927± 4,639	17.9	0 --	385± 385	0	335±335	7,600±1,582	4.4	4,906±1,346	7,119±1,673	68.9
Ponderosa and lodgepole pine	3,139± 1,161	7,028± 1,968	44.7	1,924±1,058	11,281±2,482	17.1	11,833±2,840	21,934±3,412	53.9	865±596	1,250±818	69.2
Total	220,474±11,023	774,595±30,983	28.5	3,078±1,170	36,578±4,755	8.4	15,054±3,312	123,523±9,882	12.2	20,297±3,529	47,523±5,398	42.7

[1/] No seeds were found in any traps from the 1973 seed year.

86 percent[4]. About 70 percent of the regeneration was grand fir, 27 percent Shasta red fir and the rest a mixture of ponderosa pine, lodgepole pine, and white pine.

Removing all litter and slash from subplots by bulldozing exposed mineral soil and provided the most receptive seed bed for seedling establishment. In 1975, seedling numbers on the lop and scatter, crush, and no treatment plots were similar, ranging from 3,300 to 4,000 per acre while the bulldozed plots averaged about 6,500 seedlings per acre (fig. 3B).

Analysis of the 1975 and 1978 seedling density and stocking data showed, as expected, a highly significant difference between the bulldozed treatment and the other three slash treatments for grand fir, red fir, or all species combined. Seedling establishment (all species) was also significantly greater on the high density plots than on the low or medium levels, and there was no significant interaction between overstory density levels and slash treatments. In other words, the effect of the slash treatments on seedling establishment was similar at all overstory density levels; the bulldozing treatment always resulted in considerably greater numbers of seedlings than the other treatments.

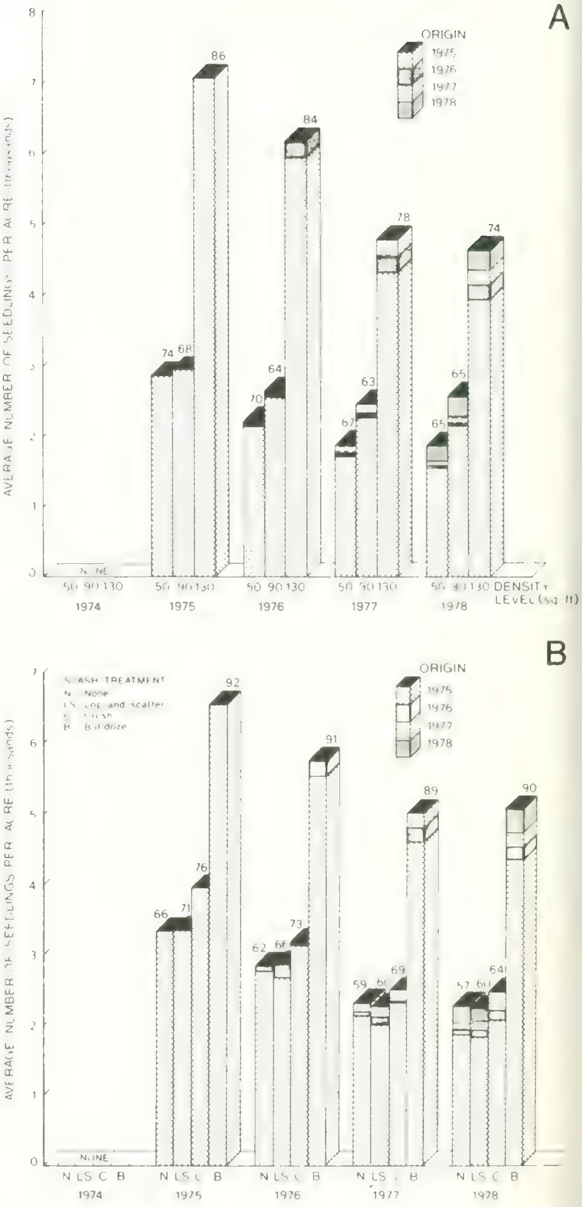


Figure 3.--Pattern of annual seedling survival (all species) from 1974 through 1978 by (A) overstory density, and (B) slash treatment. Numbers at top of bars are stocking percentages of 1-milacre quadrats.

---

[4] Quadrats were considered stocked if they contained at least one seedling.

The typical pattern of seedling invasion and mortality is illustrated in figure 3. About 30 to 40 percent of the large numbers of seedlings present in 1975 had died by 1978 with most of the mortality occuring during 1976 and 1977. Mortality rates of grand fir and red fir were similar. New seedlings were found on the plots each year from the light cone crops of 1975 through 1977 but not in sufficient numbers to offset the losses of seedlings originating in 1975. It is apparent from these results that a year of heavy cone production soon after the seed cut offers the best chance of quickly obtaining adequate natural regeneration. Although the bulk of natural regeneration generally becomes established in "waves" following heavy seed years, it is possible to obtain satisfactory stocking from light cone crops over a number of years as long as the seed bed remains receptive. Williamson (1973) also reported that adequate natural regeneration of Douglas-fir in the Cascades of western Oregon was obtained from seedling establishment during years of low seedfall. These observations suggest that it is not necessary to schedule seed cuts to coincide with heavy seed years.

In the fall of 1978, 5 years after the study was begun, all subplots were well stocked with seedlings ranging from an average of 1,220 per acre on 90 ft^2-none treatment to 7,240 per acre on the 130 ft^2-bulldoze treatment (fig. 4). Regardless of slash treatment, the high density overstory always resulted in the most regeneration. Similarly, the bulldozed subplots always contained the most seedlings regardless of overstory density level. The proportion of pine in the regeneration increased from about 3 percent in 1975 to about 11 percent in 1978 primarily because of considerable numbers of new ponderosa pine seedlings found in the fall of 1978.

Regional standards for defining satisfactory stocking of true fir regeneration have not yet been established. At this time, an estimate of adequate stocking can be obtained by using the stocking level curves for Douglas-fir which suggest 400 to 500 trees per acre as sufficient.[5] With this standard, all subplots in this study were adequately stocked after 5 years.

The sound seed-to-seedling ratio gives an indication of the environmental conditions that affect germination and early seedling survival, lower ratios indicating more favorable conditions. The superiority of the bulldozing slash treatment for obtaining natural regeneraton is shown in these ratios for the 1974 seed year

---

[5] Forest Service, Region 6, Silvicultural Examination and Prescription Handbook, 2409.26d.

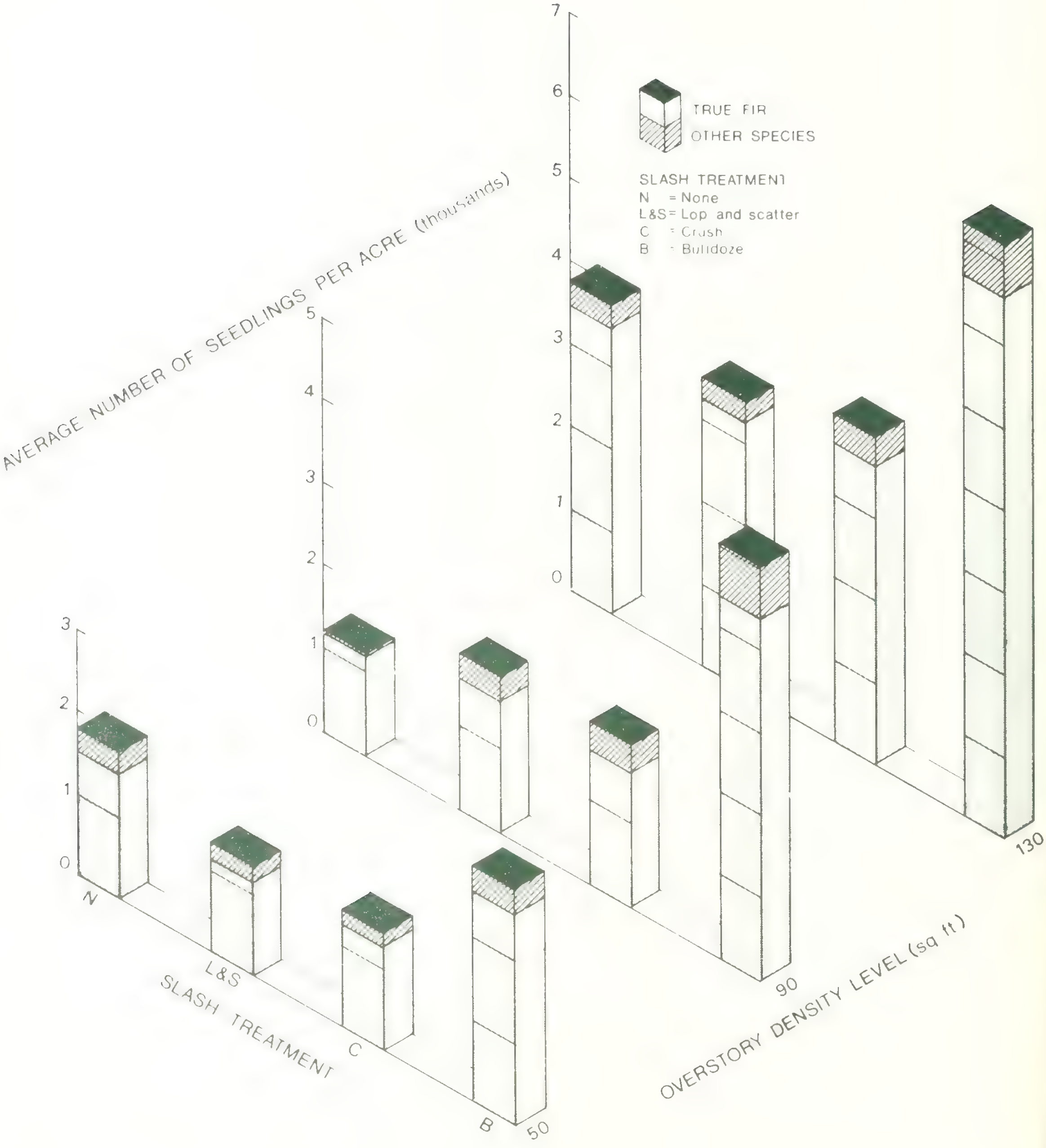


Figure 4.--Average number of seedlings per acre (all ages) established in 1978 after the fifth growing season, by overstory density, slash treatment, and species group.

(table 2). For both grand fir and red fir, the sound seed-to-seedling ratio was always the lowest for the bulldozed treatment at all density levels. Also, in all subplots, red fir was more efficient than grand fir in producing seedlings from seed having ratios some 3 to 8 times lower than grand fir. In the bulldozed subplots at the high density level, the red fir seed-to-seedling ratio was only 2:1--that is, for every two sound seeds falling in 1974, one seedling was counted in the fall of 1975.

Height growth of the fir seedlings was slow--the tallest seedlings averaging about 10 to 11 cm after 5 years (table 3). Both grand fir and red fir seedlings grew at about the same rate, and no significant differences in height existed among density levels or slash treatments. Although growth during this initial 5-year period, on the average, has been slow, many of the more vigorous seedlings showed good growth during 1978, and the rate of height growth should increase in the future (fig. 5).

Seed Bed Conditions and Regeneration

Because of the removal of nearly all organic matter on the bulldozed subplots, the percentage of milacres classified as mineral soil in 1974 was high (table 4). Litter fall during the following 5 years decreased the area of bare mineral soil and increased the number of milacres in the light litter and slash category on these subplots (fig. 6). Only minor changes in seed bed conditions occurred in the none, crush, and lop and scatter treatments since these subplots had considerable amounts of litter and slash present in 1974.

Table 2--Sound seed per seedling ratios by density level, slash treatment, and species based on 1974 seed year and 1975 seedling count

Species	Overstory density											
	50 ft^2/acre				90 ft^2/acre				130 ft^2/acre			
	Slash Treatment											
	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush
	Sound seed per seedling ratio											
Grand fir	38:1	49:1	21:1	37:1	63:1	55:1	22:1	63:1	43:1	43:1	31:1	34:1
Red fir	6:1	6:1	3:1	4:1	16:1	11.1	4:1	9:1	7:1	8:1	2:1	10.1

Table 3--Average total height of tallest seedlings per milacre, with standard errors, by species, date, overstory density, and slash treatment

Year and species	Overstory density level											
	50 ft^2/acre				90 ft^2/acre				130 ft^2/acre			
	Slash treatment											
	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush
	-Centimeters-											
1975												
Grand fir	2.7± .2	2.1± .1	2.2±.1	2.4± .1	2.9± .2	3.0± .2	3.0±.1	3.0± .2	2.4± .1	2.6± .1	2.7±.1	2.4± .1
Shasta red fir	2.3± .2	2.0± .2	2.0±--	2.9± .6	2.6± .2	2.0± --	3.0±.5	2.5± .2	2.3± .3	2.3± .3	2.5±.1	2.4± .2
1976												
Grand fir	5.5± .3	5.4± .6	4.6±.2	5.9± .4	6.3± .5	5.7± .4	5.7±.3	5.5± .4	5.4± .3	5.6± .3	6.5±.3	5.9± .3
Shasta red fir	6.3± .6	5.2± .4	4.3±.6	5.7± .6	5.0± .5	5.0± --	5.2±.4	4.8± .5	5.5± .5	4.3± .5	6.0±.3	5.7± .3
1977												
Grand fir	8.1± .6	8.2± .9	7.4±.4	9.2± .7	8.1± .7	8.5± .7	8.6±.5	7.3± .6	8.6± .6	8.6± .7	9.5±.5	7.9± .5
Shasta red fir	8.8± .6	7.2± .8	7.0±.5	9.5±1.1	8.7±1.0	9.0±1.2	8.5±.6	6.0± .3	7.9± .9	8.2±1.2	9.5±.7	10.5±1.3
1978												
Grand fir	11.0±1.1	11.3±1.4	10.1±.6	11.6±1.0	8.9±1.0	9.9±1.0	11.4±.9	8.6±1.2	9.7± .8	10.5± .9	12.2±.8	10.3± .8
Shasta red fir	9.9± .9	7.5± .9	10.2±.7	11.7±1.8	9.3± .9	10.0±1.8	10.2±.8	7.9±1.1	10.0±1.2	8.5±1.3	11.9±.9	10.4±1.6

Table 4--Percentage of milacres classified as mineral soil or having light, medium, or heavy amounts of litter and slash by density level, slash treatment, and year

Overstory density slash treatment, and year examined		Mineral soil	Litter[1]			Slash[2]		
			Light	Medium	Heavy	Light	Medium	Heavy
		----------------------	----------------------	Percent of milacres	----------------------	----------------------	----------------------	----------------------
50 ft^2/acre								
None	1974	4	52	18	12	50	36	10
	1978	4	52	20	16	44	40	10
Lop and scatter	1974	6	48	20	8	76	14	6
	1978	4	50	20	8	72	14	6
Bulldoze	1974	96	0	0	0	4	0	0
	1978	76	12	0	0	22	0	2
Crush	1974	14	34	14	2	62	24	0
	1978	8	32	16	4	64	28	0
90 ft^2/acre								
None	1974	2	34	22	18	54	18	26
	1978	2	38	26	20	54	22	22
Lop and scatter	1974	2	42	14	28	46	40	10
	1978	2	42	14	32	42	46	10
Bulldoze	1974	92	4	0	0	8	0	0
	1978	80	10	0	0	22	0	0
Crush	1974	12	52	10	4	62	18	4
	1978	4	66	6	8	70	20	4
130 ft^2/acre								
None	1974	16	28	24	2	60	20	4
	1978	6	34	22	14	62	28	4
Lop and scatter	1974	18	36	18	8	54	18	10
	1978	8	40	24	12	64	20	8
Bulldoze	1974	62	6	0	0	38	0	0
	1978	44	32	0	0	46	0	2
Crush	1974	16	56	18	0	52	16	8
	1978	12	56	20	0	66	16	6

[1] Litter:

Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.
Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.
Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generally in a compact mat, little or no mineral soil visible.

[2] Slash:

Light: Small pieces of slash covering less than 30 percent of surface.
Medium: Any size slash covering 30 to 60 percent of surface.
Heavy: Any size slash covering over 60 percent of surface.

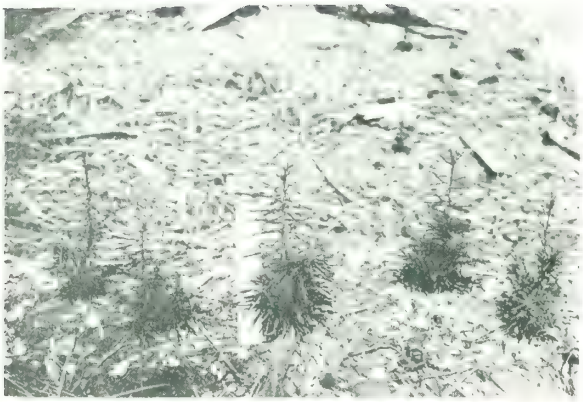


Figure 5.--Some of the taller, more vigorous grand fir seedlings in the fall of 1978. Height of rule is 15 cm.

Seedling establishment on various seed beds was generally as expected--greatest on mineral soil and decreasing as litter and slash became deeper (table 5). Generally, greater amounts of litter inhibited seedling establishment more than did increasing amounts of slash. Although a mineral soil seed bed was the most favorable for germination and survival, true fir seedlings did become established in litter and slash seed beds. I observed many seedlings throughout the study area growing in light to medium litter layers but very few in heavy compact litter mats more than 1/2 inch thick. It is clear from these results that complete litter and slash removal is neither necessary nor desirable. All that is needed is to break up continuous thick litter layers so that patches of mineral soil are present

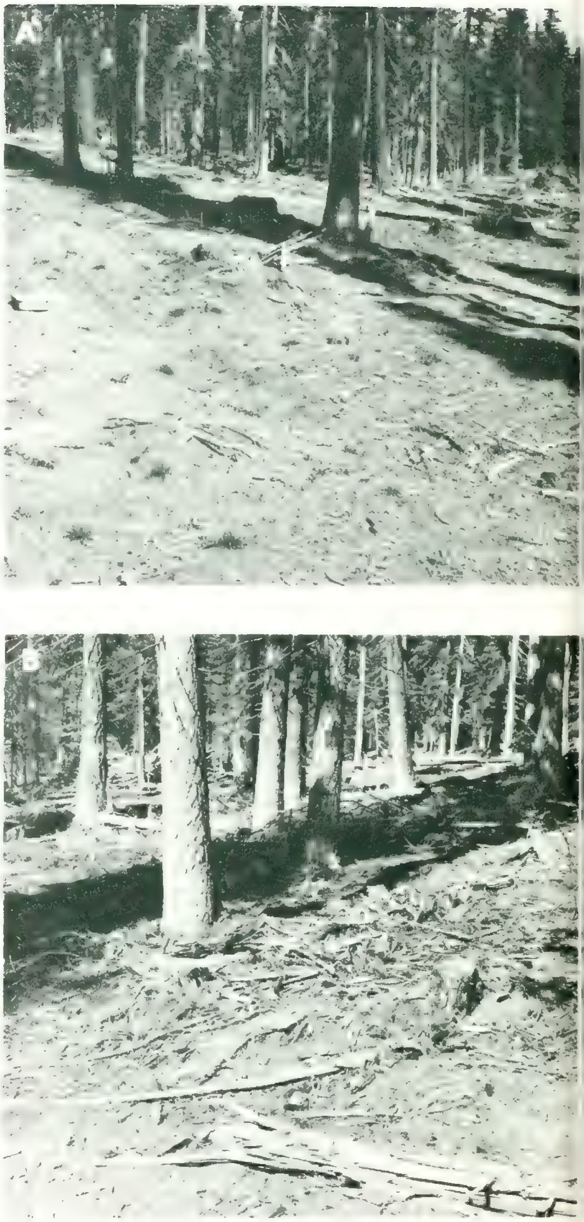


Figure 6.--Comparison of (A) bulldoze and (B) no slash treatments 5 years after treatment. Note absence of understory vegetation.

throughout the area. This is easily accomplished by logging disturbance and subsequent slash disposal operations.

Understory Vegetation

Understory vegetation was not a problem in regard to seedling establishment. In 1974, only small amounts of forbs were present on the plots and vegetation did not increase dramatically during the 5-year study period (table 6, fig. 6). Only a small number (2 to 8 percent) of milacres were classified as having medium or heavy vegetation. These results are similar to those reported by Gordon (1970) for clearcuts in true fir stands in northern California. Although in this study competition from understory vegetation was not a factor in regeneration establishment, vegetation response can be quite variable especially if seeds stored in the litter are stimulated by fire. No grazing was observed during the study period. This suggests that perhaps overstory shade had an inhibiting effect on growth of the understory.

Soil and Seedling Moisture Stress

Soil moisture was readily available to seedlings during the summer of 1975 on all plots ranging from 22 to 66 percent (weight basis) which corresponds to a soil matric potential of -0.01 to -0.1 bar (table 7). Even at the 3-inch depth, soil moisture never approached levels critical to seedling survival or growth. Precipitation during the 1975 growing season was about 2.5 inches on the study area which is about equal to the long-term summer average.

Peak moisture stress of grand fir seedlings was normal during the summer of 1975, never reaching values less than -14 bars. These soil and seedling moisture stress values are quite similar to those measured on grand fir seedlings in a fir-hemlock stand in 1973 (Seidel and Cooley 1974). It is possible, of course, that seed germination is reduced and seedling mortality occurs from rapid drying of the top few centimeters of soil.

These results indicate that once seedling roots reach a depth of 2 to 3 inches, drought is not a significant cause of seedling mortality when competing understory vegetation is absent. Gordon (1970) also concluded that because of rapid root growth of true fir seedlings, soil moisture was adequate for survival even during normally dry summers occurring in northern California.

Surface Temperatures

Surface temperatures reached levels considered lethal to seedlings on all plots. Even on high density plots, some of the 163° F (72.8° C) Tempils melted (table 8). On high density plots, there

Table 5--Average number of seedlings per milacre, with standard errors, found on milacres having none, light, medium, and heavy combinations of litter and slash by density level

Litter[1]	Overstory density level											
	$50\ ft^2$				$90\ ft^2$				$130\ ft^2$			
	Slash[2]				Slash[2]				Slash[2]			
	None	Light	Medium	Heavy	None	Light	Medium	Heavy	None	Light	Medium	Heavy
	Average number of seedlings per milacre											
None	4.6±0.6	2.0±0.3	5.0±3.0	--	5.1±0.9	3.1±0.7	3.7±2.7	--	10.7±1.1	7.4±1.2	4.5±0.5	--
Light	--	2.6±0.5	1.9±0.6	2.0±0.6	3.5±1.7	2.6±0.5	2.5±0.8	5.0±2.8	12.2±9.7	6.2±1.1	6.5±2.3	3.0±--
Medium	--	1.3±0.4	1.5±0.4	1.8±0.4	--	0.9±0.4	1.4±0.5	1.5±0.8	--	4.5±1.0	3.2±0.7	2.0±1.5
Heavy	--	--	0.9±0.6	--	--	0.5±0.5	0.6±0.2	1.4±0.8	--	3.0±--	0.4±0.2	--

---

[1] Litter:
Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.
Medium: Uniform distributions of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.
Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generaly in a compact mat, little or no mineral soil visible.

[2] Slash:
Light: Small pieces of slash covering less than 30 percent of surface.
Medium: Any size slash covering 30 to 60 percent of surface.
Heavy: Any size slash covering over 60 percent of surface.

Table 6--Percentage of milacres having light, medium, or heavy amounts of grass and sedges, forbs and shrubs by density level, slash treatment, and year

Overstory density, slash treatment, and year examined		Understory vegetation type[1]								
		Grass and sedge			Forbs			Shrubs		
		Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
		Percent of milacres								
50 ft^2/acre										
None	1974	4	0	0	30	0	2	2	0	2
	1978	16	6	0	22	0	0	22	0	2
Lop and scatter	1974	2	0	0	38	0	0	0	0	0
	1978	14	2	0	20	2	0	28	2	4
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	22	2	0	38	6	2	42	4	0
Crush	1974	2	0	0	32	2	0	0	0	0
	1978	20	0	0	34	6	0	32	6	0
90 ft^2/acre										
None	1974	0	0	0	36	4	2	0	0	0
	1978	2	2	0	16	2	0	32	8	2
Lop and scatter	1974	0	0	0	46	2	0	0	0	0
	1978	10	0	0	12	0	0	34	2	0
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	32	0	0	6	0	0	16	0	0
Crush	1974	0	0	0	32	0	0	0	0	0
	1978	22	0	0	18	2	0	14	2	0
130 ft^2/acre										
None	1974	0	0	0	8	2	0	0	0	0
	1978	10	0	0	2	0	0	10	0	0
Lop and scatter	1974	0	0	0	22	2	0	0	0	0
	1978	8	2	0	10	0	0	14	4	0
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	26	4	0	18	0	0	8	0	0
Crush	1974	0	0	0	14	0	0	0	0	0
	1978	12	0	0	12	0	0	8	0	0

---

[1] Vegetation cover classes are: light - covering 5-30 percent of milacre; medium - 30 to 60 percent; heavy - 60 percent.

Table 7--Soil moisture content (oven dry weight basis) by overstory density, depth, and date, 1975[1]

Overstory density level and depth of soil	July 1	July 16	July 28	August 12	September 3
	Percent				
50 ft^2					
3 in	38.2±0.7	35.4±1.5	25.7±3.3	28.1±10.1	30.3±9.3
6 in	37.7±6.7	38.4±0.2	33.4±2.3	38.1±0.2	29.9±3.8
12 in	44.4±1.6	46.3±1.1	45.2±4.5	47.0±0.1	47.7±4.5
18 in	51.1±4.0	58.9±0.6	59.0±5.1	57.1±0.6	51.1±7.5
90 ft^2					
3 in	35.9±1.7	42.6±1.7	27.8±4.2	32.1±8.4	27.6±5.4
6 in	37.1±6.3	38.3±2.3	36.9±2.0	35.7±5.6	35.1±6.7
12 in	41.5±2.3	47.9±0.4	40.7±2.7	40.0±1.4	39.6±4.0
18 in	58.0±5.6	60.0±16.3	60.0±18.7	55.3±9.9	56.3±3.8
130 ft^2					
3 in	45.8±1.8	42.1±5.4	22.9±1.7	41.1±9.1	21.7±5.4
6 in	41.3±0.4	42.3±1.2	41.2±1.3	35.1±2.3	31.8±6.4
12 in	46.8±14.7	45.5±7.4	43.2±2.2	42.4±0.9	44.7±3.6
18 in	65.6±3.0	58.9±0.4	55.6±1.1	53.4±4.3	56.5±0.2

[1] Each value is the mean of 3 replications. Soil matric potentials corresponding to these moisture contents were in the range of -0.01 to -0.1 bars. The soil moisture content at the -15 bar "wilting point" is about 6.0 percent.

was little difference in the percentage of 163° F (72.8° C) Tempils that melted on mineral soil and litter seed beds; but as the overstory was reduced, the temperature difference between mineral soil and litter seed beds increased. It is not the temperature alone, however, but also the duration of seedling exposure that determines mortality. Therefore a mineral soil seed bed becomes increasingly important at lower stand densities because the soil surface will be exposed to full sunlight for a longer time. Although surface temperatures were in the lethal range for young seedlings, no data are available regarding the length of exposure to these tem-

Table 8--Surface temperature, by overstory density and seed bed condition[1]

Seed bed condition	Tempil melting point (^{o}F)			
	125	138	150	163
	Percent of pellets melted			
	50 ft^2/acre			
Mineral soil	100	100	60	20
Litter	100	100	100	70
	90 ft^2/acre			
Mineral soil	100	100	43	13
Litter	100	100	93	87
	130 ft^2/acre			
Mineral soil	100	100	33	10
Litter	100	100	47	13

[1] Each value is the mean of 3 replications.

peratures or the reponse of true fir seedlings to various high temperature-time combinations. Therefore, although it is likely that high surface temperatures were a factor in seedling mortality, the actual importance of these lethal temperatures cannot be determined.

Overstory Mortality

Of the 210 residual overstory trees left on the plots after logging in 1973, 17 were lost during the 5-year study period--12 were blown down and 5 died--apparently from exposure shock. Overstory mortality was not related to residual stand density; four trees were lost in the low density plots, eight in the medium density, and five in the high density. In unmanaged old-growth stands such as these, trees have not developed the windfirmness needed to resist greater wind stresses resulting from partial cuts. The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees which are the most windfirm and also the best seed producers (Gordon 1973).

CONCLUSIONS

The use of the shelterwood system in this mixed conifer stand was successful in obtaining natural regeneration at each of the three overstory density levels. Most seedlings were established on subplots where mineral soil was completely exposed, but regeneration was also adequate on seed beds where compact litter mats were broken up and litter and duff did not exceed 1/2 inch in depth. Complete litter and slash removal is not necessary or desirable since a suitable seed bed is provided by logging and slash disposal operations which break up heavy litter and duff layers and expose mineral soil. It appears that the species composition of the reproduction will be similar to that of the old-growth stand; about 85 percent true fir and 15 percent ponderosa, lodgepole, and white pine. The bulk of the regeneration occurred from one heavy seed crop during the 5-year period. Because of the absence of competing understory vegetation, however, the seed bed remained receptive throughout the 5-year study period, and some seedlings became established every year. Most of the seedling mortality took place during the first 2 years after the heavy seedfall and apparently was caused by high surface temperatures rather than drought.

Determination of suitable residual stand density to leave after the seed cut when using the shelterwood system depends upon the amount of natural regeneration expected and the subsequent loss of established seedlings when the residual overstory is removed. Obviously, no more trees than necessary to obtain adequate regeneration should be left after the seed cut because avoiding mortality and damage to reproduction during overstory removal and slash disposal generally becomes more difficult as overstory density increases. In this specific study area (a mixed conifer/manzanita community with a south aspect) it appears that a residual overstory basal area of about 50 ft^2 per acre is sufficient to provide adequate natural regeneration within a 5-year period. Studies are currently underway to evaluate shelterwood regeneration in several plant communities and various aspects, slopes, etc. In order to minimize windthrow losses of the residual overstory, only the best dominant and codominant, fully crowned trees should be left after the seed cut. This can be more easily accomplished by marking the leave trees rather than the cut trees because the marker's attention is then focused on the most desirable trees to leave.

Removal of the overstory and slash disposal without excessive loss or damage to the established reproduction is critical to the successful application of the shelterwood system. Barrett et al. (1976) have shown that it is possible to preserve adequate numbers of understory ponderosa pine saplings on level topography while removing 24,000 board feet per acre. It should also be possible to remove 50 ft^2 of basal area from mixed conifer stands in gentle topography while saving enough reproduction for a manageable stand. Skillful application of logging techniques and good coordination between timber and fuel management staffs are essential to achieve this objective.

The overstory will be removed from the plots in this study in about 3 years. At that time, the effect of several logging and slash disposal methods on seedling survival will be evaluated.

LITERATURE CITED

Barrett, James W., Stanley S. Tornbom, and Robert W. Sassaman.
1976. Logging to save ponderosa pine regeneration: A case study. USDA For. Serv. Res. Note PNW-273, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F.
1965. Ecology and silviculture of the true fir-hemlock forests of the Pacific Northwest. Soc. Am. For. Proc. 1964:28-32, illus.

Franklin, Jerry F., Richard Carkin, and Jack Booth.
1974. Seeding habits of upper-slope tree species. I. A 12-year record of cone production. USDA For. Serv. Res. Note PNW-213, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gordon, Donald T.
1970. Natural regeneration of white and red fir....influence of several factors. USDA For. Serv. Res. Pap. PSW-58, 32 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T.
1973. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clear-cuttings. USDA For. Serv. Res. Pap. PSW-90, 22 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gratkowski, H. J.
1958. Natural reproduction of Shasta red fir on clear cuttings in southwestern Oregon. Northwest Sci. 32:9-18.

Schumacher, Francis X.
1926. Yield, stand, and volume tables for white fir in the California pine region. Univ. Calif., Coll. Agric., Agric. Exp. Stn. Bull. 407, 26 p. Berkeley, Calif.

Seidel, K. W., and R. Cooley.
1974. Natural reproduction of grand fir and mountain hemlock after shelterwood cutting in central Oregon. USDA For. Serv. Res. Note PNW-229, 10 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. USDA For. Serv. Pac. Northwest Reg. 6 Area Guide 4-2, 110 p., illus.

Waring, Richard H. and Brian D. Cleary.
1967. Plant moisture stress: Evaluation by pressure bomb. Science 155:1248, 1253-1254, illus.

Williamson, Richard L.
1973. Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. USDA For. Serv. Res. Pap. PNW-161, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

APPENDIX

Table 9--Average number of seedlings per acre (all ages), with standard errors and stocked milacre percentage by density level, slash treatment, species, and year

Year, species and milacre stocking	Overstory density level											
	50 ft^2/acre				90 ft^2/acre				130 ft^2/acre			
	None	Lop and scatter	Crush	Bulldoze	None	Lop and scatter	Crush	Bulldoze	None	Lop and scatter	Crush	Bulldoze
	Number of seedlings per acre ± standard error											
1975												
Grand fir	1,600±576	1,240±322	1,620±518	2,900±725	1,260±517	1,440±432	1,260±315	3,600± 900	4,960±1,165	4,980±1,220	6,225±1,898	6,780±1,186
Shasta fir	660±231	680±238	1,000±260	1,440±295	480±173	720±342	860±271	1,800± 333	780± 253	680± 255	575± 258	2,880± 518
Lodgepole and ponderosa pine	100± 66	--	20± 20	40± 40	20± 20	60± 50	40± 40	60± 50	80± 60	125± 94	95± 80	40± 40
White pine	20± 20	--	60± 40	40± 40	--	20± 20	20± 20	80± 60	--	45± 40	65± 55	20± 20
Total	2,380±714	1,920±422	2,700±702	4,420±884	1,760±554	2,240±706	2,180±436	5,540±1,108	5,820±1,338	5,830±1,282	6,960±1,914	9,720±1,555
Stocked milacres-percent	68	68	72	90	48	62	72	90	82	[illegible]	85	[illegible]
1976												
Grand fir	1,260±416	880±194	1,260±328	2,140±492	980±343	1,400±406	1,040±206	3,400± 816	4,440± 977	4,220± 971	5,485±1,590	[illegible]
Shasta fir	600±230	440±155	600±156	1,120±224	400±128	660±284	560±112	1,720± 310	620± 198	600± 228	250± 95	2,440± 390
Lodgepole and ponderosa pine	100± 66	40± 30	60± 40	40± 40	20± 20	60± 40	40± 40	80± 60	100± 66	180± 60	70± 60	40± 40
White pine	20± 20	--	60± 40	40± 40	--	40± 35	20± 20	100± 66	--	45± 40	85± 65	80± 60
Total	1,980±535	1,360±272	1,980±455	3,340±534	1,400±364	2,160±648	1,660±276	5,300± 954	5,160±1,084	5,045±1,059	5,890±1,590	8,600±1,204
Stocked milacres-percent	66	58	70	88	43	58	68	88	76	[illegible]	[illegible]	[illegible]
1977												
Grand fir	1,140±342	760±160	820±164	1,820±346	760±217	1,200±300	1,020±202	3,240±745	3,280±590	3,025±666	3,790±1,023	4,800±650
Shasta fir	520±175	420±140	500±130	920±178	320± 72	520±196	620±140	1,460±200	560±179	440±168	190± 66	[illegible]
Lodgepole and ponderosa pine	100± 66	80± 60	100± 66	60± 40	20± 20	40± 35	40± 40	180± 62	140± 80	140± 80	225± 90	240± 80
White pine	20± 20	20± 20	60± 40	60± 40	--	60± 40	80± 60	160± 60	60± 40	80± 60	40± 40	80± 60
Total	1,780±445	1,280±243	1,480±278	2,860±363	1,110±229	1,820±423	1,760±293	5,040±779	4,040±687	3,685±700	4,245± 998	7,120±742
Stocked milacres-percent	66	52	64	86	38	58	70	86	72	[illegible]	[illegible]	[illegible]
1978												
Grand fir	1,040±284	780±160	900±186	1,700±287	740±212	1,100±245	1,040±206	3,060±676	2,900±500	2,880±602	3,445± 910	4,680±633
Shasta fir	480±125	380± 94	400±107	920±178	460±103	520±196	620±140	1,400±192	580±185	365±139	[illegible]	1,900±255
Lodgepole and ponderosa pine	260± 80	160± 60	80± 60	280± 76	20± 20	260±114	260± 94	420± 91	220± 87	205± 70	320± 139	540±152
White pine	20± 20	20± 20	60± 50	20± 20	--	20± 20	60± 40	180± 62	60± 40	55± 45	45± 40	[illegible]
Total	1,800±410	1,340±233	1,440±270	2,920±371	1,220±254	1,900±442	1,980±330	5,060±782	3,760±615	3,505±657	4,005± 942	7,240±755
Stocked milacres-percent	64	54	56	86	36	62	72	91	72	64	[illegible]	[illegible]

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon

La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
809 N.E. 6th Ave.
Portland, Oregon 97232

Seidel, K. W.
1979. Natural regeneration after shelterwood cutting in a grand fir-Shasta red fir stand in central Oregon. USDA For. Serv. Res. Pap. PNW-259, 23 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Natural regeneration was good to excellent 5 years after shelterwood cutting to three overstory densities (50, 90, and 130 ft^2 per acre) in a mixed conifer stand on the Deschutes National Forest in central Oregon. Seedling density ranged from about 1,875 per acre on the low density plots to 4,627 per acre on the high density plots and consisted of about 85 percent true fir (grand and Shasta red) and 15 percent ponderosa, lodgepole, and western white pine. Mineral soil was the most favorable seed bed for germination and seedling survival, but many true fir seedlings did become established in light to medium litter layers. A residual overstory of about 50 ft^2 of basal area per acre appears adequate to provide natural regeneration within a 5-year period.

KEYWORDS: Shelterwood cutting method, regeneration (natural), grand fir, Abies grandis, Shasta red fir, Abies magnifica var. shastensis, Oregon (central).

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

U.S. Department of Agriculture
Forest Service
Pacific Northwest Forest
and Range Experiment Station
Research Paper PNW-260
July 1979

Winter Diets of Elk and Deer in the Blue Mountains, Oregon

Jon Skovlin and Martin Vavra

GOVT. DOCUMENTS
DEPOSITORY ITEM
DEC 14 1979
CLEMSON
LIBRARY

CLEMSON UNIVERSITY LIBRARY
DEC 17 1979
TECH. & AGR. DIV.

AUTHORS

JON SKOVLIN is research biologist, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, La Grande, Oregon.

MARTIN VAVRA is associate professor, Eastern Oregon Agricultural Research Center, Oregon State University, Union, Oregon.

ACKNOWLEDGMENT

The authors express their appreciation to area biologists of the Northeast Region of the Oregon Department of Fish and Wildlife for field collections and site information.

WINTER DIETS OF ELK AND DEER IN THE BLUE MOUNTAINS, OREGON

Reference Abstract

Skovlin, Jon, and Martin Vavra. 1979. Winter diets of elk and deer in the Blue Mountains, Oregon. USDA For. Serv. Res. Pap. PNW-260, 21 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

From an analysis of fecal pellets, diets of elk and deer were compared during early and late winter of 1973-74 to determine the level of competition. Forage competition between elk and deer was not great even though winter conditions were harsher than normal on the five dual-use winter ranges studied. Shrubs were not as important here as in other winter range areas of the West. Idaho fescue was the single most important item in their diets.

KEYWORDS: Food habits (wildlife), range management, cervidae, Blue Mountains (Oregon), forage management.

RESEARCH SUMMARY

Research Paper PNW-260

1979

Dietary contents of pellet droppings from elk and deer were analyzed from collections on five winter-range units throughout the Blue Mountains during early and late winter of 1973-74. Botanical intake was identified by species to establish levels of elk and deer competition for food. Elk consumption of grasses during early and late winter was slightly over one-half and three-quarters of their total intake, and deer use of grass early and late was about one-third and one-half of their intake. Forb use by both elk and deer was insignificant. Elk diets contained less than 25 percent shrubs. Shrubs are apparently not as important to elk and deer in the Blue Mountains as they are on other winter ranges of the mountain west. Conifer use by deer, especially, was high on two winter range units when snow was in excess of 1 foot and temperatures near zero. Idaho fescue was the most often selected species by both animals. Competition for available forage species was not acute under the moderately severe winter conditions that prevailed.

CONTENTS

LITERATURE REVIEW 2

STUDY AREA 3

METHODS 5

RESULTS 6
  Three-Factor Analysis 7
  Two-Factor Analysis 8
    Walla Walla Unit 10
    Umatilla Unit 10
    Minam Unit 10
    Heppner Unit 11
    Ukiah Unit 11

DISCUSSION 12
  Diet Overlap 12
  Plant Values 12
  Winter Diet and Animal Behavior 14
  Animal Interaction and Nutrition 14

SUMMARY AND CONCLUSIONS 15

LITERATURE CITED 16

APPENDIX 20

The northern Blue Mountains of Oregon and Washington provide year-round forage supplies for one of the most densely populated elk herds in North America; they also support a substantial population of mule deer.

Wildlife biologists and habitat managers have long recognized the probability of competition between Rocky Mountain elk (*Cervus canadensis nelsoni*) and Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) for forage on winter ranges in the Blue Mountains (Cliff 1939, Buechner 1952). Elk, because of their greater size, mobility, and foraging capability, have an advantage over deer when wintering conditions become severe. The extent of competition between elk and deer for local plant species, however, is not known.

Summer ranges, though obligated for livestock grazing, do not usually present competition problems among big game animals nor between big game and livestock (Edgerton and Smith 1971, Miller 1974, Skovlin et al. 1976), except in isolated situations (Pickford and Reid 1943). Summer ranges are mainly public land, whereas most winter ranges are private land. Although not a subject of this investigation, summer or fall grazing of foothill range by cattle prior to winter use by elk and deer may create local winter food shortages under situations of poor management.

Certain areas in winter or summer in northeastern Oregon may be better suited to the production of deer than of elk because of habitat or forage conditions. Larger numbers of elk on some common-use big-game ranges may jeopardize survival of deer in hard winters. Until recently, no effective method of separating the forage preference of elk from that of deer has been feasible. Analysis of rumen contents is possible but costly in terms of laboratory analysis and animals sacrificed, and it has not been accomplished.

Recent developments in microscopic analysis of fecal material through the use of epidermal plant keys--a relatively inexpensive, suitable method--has made comparisons of diets possible (Ward 1970). Preference ratings derived from this technique are valid for comparing the relative ranking of plant species selected. Absolute values in terms of quantity, however, may vary somewhat by season, plant succulence, or major plant groups; i.e., grasses, forbs, or browse.

The objectives of this study were to (1) determine winter diets of deer and elk, (2) establish whether or not competition for forage on winter range existed between elk and deer, and (3) if it exists, quantify the extent of diet overlap between animal species.

LITERATURE REVIEW

Competition for forage between animal species occurs when two or more species prefer the same food items and the supply or area is limited. Several reviews of the literature have listed the numerous studies reporting on food habits of elk and deer (Capp 1968, Kirsch and Greer 1968, Kufeld 1973, Kufeld et al. 1973). Only a few studies, however, have attempted to identify competition on common-use winter range over a broad regional area, such as the Blue Mountains.

Working on the North Fork of the John Day River in the southern Blue Mountains, Cliff (1939) suggested that "feeding habits of mule deer and elk are quite similar in this region." He also observed that deer have a tenacious instinct to use customary feeding areas in winter but elk would seek out new areas of available forage in hard winters. Early studies of winter range in nearby Idaho also warned that increasing elk numbers presented a threat to resident deer populations (Case 1938).

Based on 3 years of data from analysis of stomach contents of elk and deer in Idaho and western Montana, DeNio (1938) showed that elk preferred winter diets consisting mainly of grasses but that mule deer preferred mainly shrubs and conifers. Availability of preferred species has been shown to influence the composition of elk and deer diets (Morris and Schwartz 1957). Cowan (1947) concluded from studies of feeding time on plants in Jasper National Park, Alberta, that elk were forcing mule deer to shift their winter diets from preferred browse to grass.

Studies of different densities of elk and deer on Blue Mountain winter range in southeastern Washington showed that high elk concentrations could inhibit recovery of the range but that competition for the principal bunchgrass species was probably not severe (Buechner 1952).

Studies of reproduction of both elk and deer have pointed out the several physiological responses that reduce densities of herds when shortages in the food supply become chronic (Buechner and Swanson 1955, Klein 1970, Robinette et al. 1977).

STUDY AREA

The physiographic province of the Blue Mountains of eastern Oregon and Washington is the second largest in the two-State area; the largest is the Columbia Basin which joins the mountain foothills on the north and west. It is at this interface that critical winter range exists (fig. 1). Within the mountains, however, are large, block-faulted valleys, the foothills of which also provide winter forage for more localized herds of elk and deer. Maximum migration of elk from the Columbia Basin winter range at 2,000 feet (600 m) elevation to high summer range at 8,000 feet (2 500 m) elevation is about 40 miles (65 km). Interior migrations are over elevation changes of 2,000 to 3,000 feet (600-900 m) and distances of 5 to 10 miles (8 to 16 km). Specific study sites shown in figure 1 are listed in table 1.

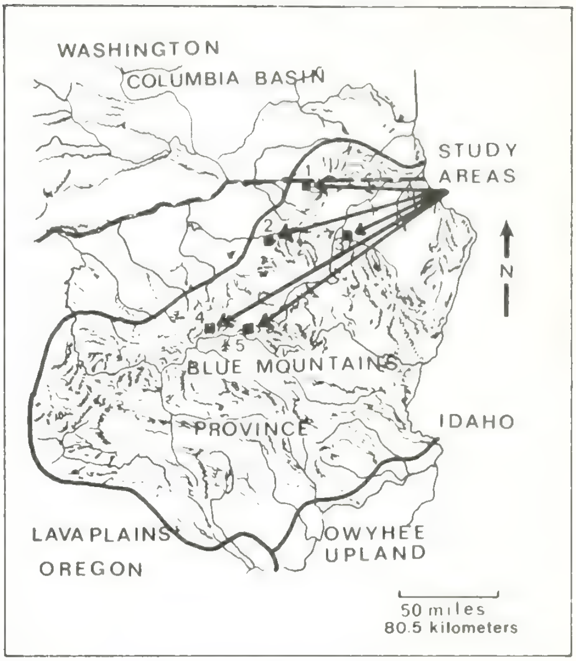


Figure 1.--A physiographic map of the Blue Mountains shows the five locations of elk and deer winter range where early and late diet sampling was studied (study area numbers correspond to those in tables 1 and 3-5).

Table 1--Winter range study areas within Blue Mountain management units where elk and deer competition for forage was most likely acute

Study area	River basin	Sample site	Location[1]	Mean elevation	
				Feet	Meters
1. Walla Walla	Walla Walla	Flume Canyon	T. 5 N., R. 37 E.	2,000	610
2. Umatilla	Umatilla	Meacham Creek	T. 2 N., R. 36 E.	2,000	610
3. Minam	Grande Ronde	Wallowa River	T. 2 N., R. 41 E.	2,500	762
4. Heppner	John Day	Ditch Creek	T. 7 S., R. 28 E.	3,500	1 067
5. Ukiah	John Day	Bridge Creek	T. 6 S., R. 31 E.	3,500	1 067

[1] Based on the Willamette meridian.

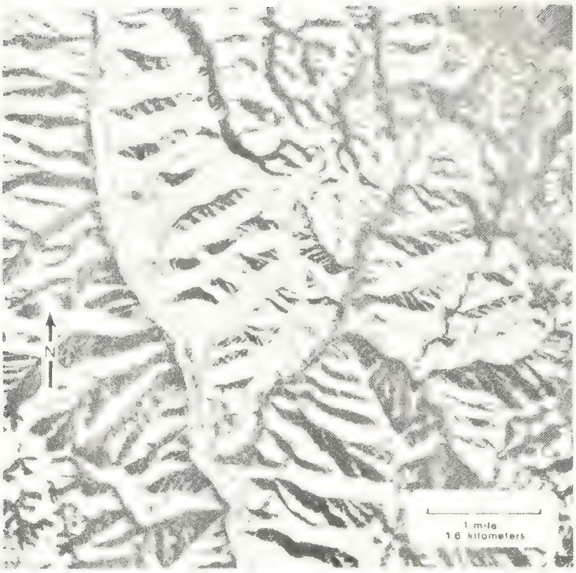


Figure 2.—An aerial photo of the Umatilla winter-range sampling area (area 2 in fig. 1 and table 1) illustrates typical canyon relief and shows the intermingled arrangement of forest and grassland communities.

The Blue Mountains consist of a large, arched syncline, uplifted from basalts of the Columbia Basin floor. At foothill elevations over about 3,000 feet (900 m) winter-range areas consist of north slopes covered with mixed pine-fir forest and south slopes with open bunchgrass and scattered pine (fig. 2).

Grassland soils range from the lower prairie type chernozems of the Palouse formation to the shallow basalt lithosols of the intermingled upland forest openings. Forest soils are predominantly western brown forest soils with inclusions of wind-transported pumicite from earlier volcanism in the Cascade Range.

Climate is influenced mostly by marine airmasses from the Pacific Ocean which furnishes precipitation having a winter high and a summer low. Along lower foothills and mountain valleys, precipitation is mainly rainfall in amounts of 10 to 15 inches (25-38 cm), with a spring peak in May. Fall rains initiate regrowth of grassland forage in about 3 out of 4 years. In the mountains, precipitation ranges between 20 and 40 inches (51-102 cm) and is largely in the form of snow that accumulates beginning in November.

In late fall, deer precede elk from the mountains to these winter ranges. Elk remain on the summer range into December, and it is often January before snow depth drives them down onto foothill winter range. Depending on spring "breakup" and initial growth of forage, elk begin migrating from winter range between mid-March and early April. Deer may linger longer, but both species are usually off winter range by late April. Normally, Blue Mountain winter ranges provide between 3 and 4 months of concentrated use by big game.

Winter forage is derived from a variety of habitats. These are broadly characterized by the foothill grassland and ponderosa pine[1] savannah types with inclusions of Douglas-fir on the moist, north slopes. Cheatgrass is a common invader in all grassland associations. In abundance, it is largely an indicator of poor range condition caused from past heavy grazing by livestock (Griffiths 1902). Range fires, more common in the past, are still a feature of community development.

Foothill grasslands consist mainly of three associations, (1) the bluebunch wheatgrass/Sandberg bluegrass, (2) bluebunch wheatgrass/Idaho fescue, and (3) Idaho fescue/snowberry (Daubenmire 1970). Herbaceous species common to all study areas were: bearded bluebunch wheatgrass, cheatgrass, Idaho fescue, onespike danthonia, prairie junegrass, and Sandberg bluegrass. Forbs included balsam root, erigeron (fleabane), lomatium (biscuitroot), lupine, onion, rushpussytoes , stoneseed, and western yarrow. Shrubs included buckwheat (Wyeth eriogonum), chokecherry, rabbitbrush, rose, sagebrush, and snowberry.

Forest communities associated with these winter ranges include the (1) ponderosa pine/bluebunch wheatgrass, (2) ponderosa pine/Idaho fescue, (3) ponderosa pine/snowberry, and (4) ponderosa pine/ninebark (Daubenmire and Daubenmire 1968); components of the Douglas-fir/snowberry and Douglas-fir/pinegrass associations also exist in small amounts. In addition to many of the above grassland species, forest type herbaceous species included: cheatgrass, elk sedge, hawkweed, heartleaf arnica, letterman needlegrass, northwest sedge, pinegrass, rose pussytoes, Ross sedge, strawberry, western fescue, and western needlegrass. Common shrubs of the forest were: chokecherry, creambush rockspirea, oceanspray, Oregon grape, and ninebark. Trees included: Douglas-fir, ponderosa pine, and western juniper.

The salient feature of winter range in and surrounding the Blue Mountains is that the classical type shrub communities often associated with other big-game winter range throughout the Rocky Mountains and intermountain west are absent.

METHODS

In consultation with the Oregon Department of Fish and Wildlife, Northeast Region, 5 winter range units of a possible 25 were selected to represent ranges having the highest probability for competition between deer and elk (fig. 1). Biologists managing wildlife on these areas were given material and sampling instructions for early and late winter collections of fecal pellets. Early sampling was done during the inventory of herd composition in December of 1973; the late season collection was from the same sampling sites but during March and April of 1974 when population trends were determined.

---

[1] Scientific plant names are listed in the appendix.

Field biologists gathered the freshest possible fecal pellet groups for each collection. Four groups each for elk and deer were collected from the five areas during early and late season for laboratory analysis. Samples were kept frozen from the time of collection until they were analyzed.

Analysis followed the technique of Sparks and Malechek (1968). Some modification in preparation of samples made material placed on microscope slides more color free. Pellets were put in a blender with ethanol and blended at low speed for 1 minute to homogenize the sample. The resulting solution was allowed to soak for 24 hours, and the ethanol was poured off. Fecal material was then dried in a forced air oven. When completely dry, the material was ground through an intermediate Wiley mill fitted with a 1-mm screen.[2] After the samples were ground, they were soaked in water for 3 hours and put in a blender for 2 minutes at high speed. Samples were poured from the blender through a 200-mesh screen and washed in water to remove fine material. Three microscope slides were prepared from the washed material. Twenty fields on each of the three slides were the basis for observation.

A factorial analysis of variance was applied to specific constituents making up most of the diets. Data were pooled in two ways. A two-factor analysis was run so that species and seasons within areas could be compared. A three-factor run considered areas, seasons, and species. Results from the Walla Walla study area did not fit the data set and were deleted from this analysis. Unique features of this area were the unusually high amounts of pinegrass, sagebrush, and Douglas-fir that were not common or present in the other four areas.

Kulcyznski's formula found in Oosting (1956) was used to compare deer and elk diets for degree of overlap. Hansen and Reid (1975) applied the formula to analysis of food habits.

To aid interpretation of the data, we examined weather records from three local stations[3] to correlate possible storm periods with the dates of field inventory.

RESULTS

The weather records showed that conditions during the 1973-74 sampling periods were somewhat more severe than those of the previous 10-year period (fig. 3). December 1973, the month of early sampling, had temperatures 6°F (2.9°C) below the monthly December mean for the previous decade. March, the month of late sampling, had near normal temperatures. Precipitation

---

[2] Mention of products by name is for the information and convenience of the reader and does not constitute an official endorsement by the U.S. Department of Agriculture to the exclusion of other suitable products.

[3] Official weather stations were Meacham, Minam, and Ukiah, Oregon; each located within several miles of the Umatilla, Minam, and Ukiah study areas, respectively (see fig. 1 and table 1).

(primarily snow) for these two periods was approximately 150 and 110 percent, respectively, of the 10-year average.

Three-Factor Analysis

By the three-factor analysis, we compared differences in selection of plant species (1) among areas and (2) between elk and deer for (3) early or late seasons. Differences for the three-factor analysis of variance are shown in table 2.

Elk consumed more bluebunch wheatgrass (P<0.05) than did deer. Also, slightly more of this grass (P<0.10) was consumed during the later period.

Use of elk sedge was sporadic and generally light over areas, seasons, and species. Only elk consumed much elk sedge and then only late in the Minam unit and early in the Heppner unit.

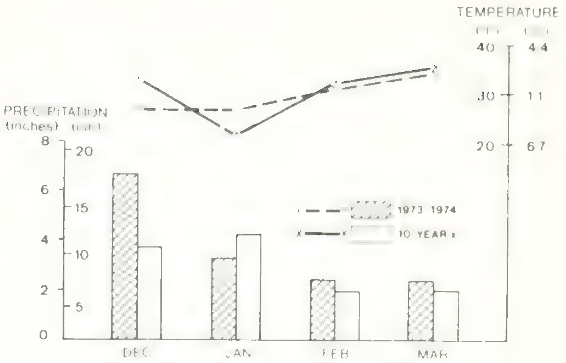


Figure 3.--A comparison of average monthly temperatures and precipitation for the winter of 1973-74 with the previous 10-year period shows weather conditions for the year of study were somewhat more harsh than those of the previous decade.

Idaho fescue was consumed more (P<0.05) by elk than deer. Use in the Walla Walla unit was high by both game species. Idaho fescue was the most important single species consumed by elk over all areas and seasons.

Table 2--Differences among selected diet constituents resulting from the three-factor analysis of variance as shown by F values and levels of significance[1]

Species and groups	Study areas[2] (1-4)	Species (elk-deer)	Season (early-late)	Interaction (species-season)
Bluebunch wheatgrass	2.155	10.585**	4.268**	1.040
Elk sedge	.838	5.830	.281	.008
Idaho fescue	1.238	5.741**	2.842	.367
Sandberg bluegrass	2.919*	3.991*	2.376	3.353*
All grasses	2.775	7.072**	8.427**	.130
All browse	3.442*	7.960**	.039	.037
Ponderosa pine	2.834*	3.007	2.584	.995

---

[1] * P<0.10; ** P<0.05; *** P<0.01.

[2] Data from area 5, the Walla Walla unit, were not included in this analysis because it was unique in terms of diet selection.

Table 3--Differences among selected diet constituents resulting from the 2-factor analysis of variance as shown by F values and level of significance[1]

Study area and variable	Bluebunch wheatgrass	Elk sedge	Idaho fescue	Sandberg bluegrass	All grasses	All browse	Ponderosa pine
Walla Walla:							
Season	0.140	0.134	0.518	2.658	0.146	0.198	0.672
Species	.427	1.948	1.359	2.118	5.771**	5.311**	.687
Interaction	6.165**	.071	1.195	3.588*	1.385	.025	1.795
Umatilla:							
Season	.540	5.483**	9.686***	1.000	25.395***	.004	9.750***
Species	1.286	2.437	.018	1.000	.406	1.643	14.361***
Interaction	.224	1.243	.001	1.000	.055	1.476	19.293***
Minam:							
Season	1.031	2.068	7.198**	1.921	15.608***	2.126	47.402***
Species	.255	3.196*	5.836**	1.921	4.657*	3.122	4.037*
Interaction	.071	.581	4.274*	1.921	.220	2.442	3.585*
Heppner:							
Season	1.208	1.893	34.703***	5.644**	7.953**	4.001*	.893
Species	6.205**	3.793*	51.513**	7.537**	9.839***	53.768***	.825
Interaction	.822	1.893	32.886**	9.680***	.609	1.581	1.095
Ukiah:							
Season	.092	.702	.970	4.244**	2.424	.521	2.066
Species	2.404	1.610	37.378***	14.009***	39.780***	7.167**	16.079***
Interaction	.092	.901	.612	5.687**	.440	.378	.683

[1] * P<0.10; ** P<0.05; *** P<0.01.

For Sandberg bluegrass, slight differences (P<0.10) were noted for area, species, and species-season interaction. In the Heppner and Ukiah units, elk consumed more Sandberg bluegrass early and deer consumed more during the later period. Sandberg bluegrass was only consumed in small quantities by deer in the Minam unit and by elk in the Umatilla unit.

In summary, elk consumed more grass (all grasses) (P<0.05) in their diet than did deer. Both game species consumed more grass (P<0.05) during the late period. Browse (all browse) consumption by deer was greater (P<0.05). Both deer and elk consumed more browse in their diets on the Heppner unit than elsewhere. Ponderosa pine consumption varied slightly among areas (P<0 10). Both deer and elk consumed large amounts of pine needles from the Minam and Umatilla units.

Two-Factor Analysis

By the two-factor analysis, we compared deer and elk diets within each area. Comparisons between animal species and seasons were tested, along with their interactions (table 3). Diet means (percent) are presented for comparison in table 4.

Table 4--Mean diet composition of selected species and forage groups by area, species, and season[1]

Study area and species	Season	Bluebunch wheatgrass	Elk sedge	Idaho fescue	Sandberg bluegrass	All grasses	All browse	Ponderosa pine
					Percent			
Walla Walla:								
Elk	Early	13	1	21	1	90	4	3
	Late	32	2	17	30	95	2	1
Deer	Early	29	0	22	5	82	13	1
	Late	4	0	42	2	72	12	7
Umatilla:								
Elk	Early	5	1	2	0	11	1	10
	Late	13	5	47	1	71	6	22
Deer	Early	0	0	0	0	0	13	87
	Late	2	2	44	0	66	6	16
Minam:								
Elk	Early	2	7	2	0	17	1	65
	Late	4	21	22	0	61	0	25
Deer	Early	0	0	0	0	1	3	96
	Late	3	4	3	4	35	37	26
Heppner:								
Elk	Early	6	28	10	12	70	16	9
	Late	10	4	56	4	90	8	4
Deer	Early	0	0	2	7	28	66	4
	Late	1	0	2	42	49	45	4
Ukiah:								
Elk	Early	1	2	73	1	93	0	6
	Late	1	8	56	0	86	1	11
Deer	Early	0	0	6	6	51	7	32
	Late	0	0	4	23	34	11	50

---

[1] Means for all grasses, all browse, and ponderosa pine should approach 100 percent; however, differences are due to other less important diet constituents.

Walla Walla Unit

Bluebunch wheatgrass was important to both elk and deer on this unit. A significant species-season interaction (P<0.05) for bluebunch wheatgrass was observed; elk consumption of wheatgrass came late, but deer use was early. Idaho fescue was also important, both early and late, to elk and deer. Neither elk sedge nor ponderosa pine were important constituents of the diet. Elk consumed more Sandberg bluegrass late than did deer; deer consumed more early than did elk; this species-season interaction was apparent (P<0.10). Early and late diets were composed of 90 and 95 percent grasses for elk; for deer, 82 and 72 percent. Pinegrass contributed heavily to both elk and deer diets on this unit. This suggests little preferred forage was available on the Walla Walla area because pinegrass is below 3-percent protein at this time of year (Skovlin 1967).

Deer consumed significantly more browse (P<0.05) in their diets than did elk. Sagebrush was the most common species consumed early and ninebark was the most common consumed late.

Umatilla Unit

Bluebunch wheatgrass, elk sedge, and Sandberg bluegrass were not important diet constituents in this unit. Late season elk and deer diets were, however, composed of 47 and 44 percent Idaho fescue, respectively. Considerably less fescue (P<0.01) was consumed by both species during the early period.

Consumption of all grasses was similar for both species. Late diets contained considerably more grass (P<0.01). More browse species were consumed by deer than by elk. Oregon grape made up most of the browse portion of the diets. Both deer and elk consumed 6 percent browse in their late diets. Deer used more ponderosa pine (P<0.01) than elk did during the early period; but during the late period its incidence in diets of both animals was similar.

Minam Unit

Both bluebunch wheatgrass and Sandberg bluegrass were minor diet constituents of deer and elk in the Minam unit. Elk diets contained slightly more elk sedge (P<0.10) and more Idaho fescue (P<0.05) than deer diets did. Both plant species were used primarily during the late period.

Grasses accounted for slightly more ($P<0.10$) of the elk diets than of the deer diets. Both deer and elk consumed considerably more grass ($P<0.01$) during the late sampling period.

Browse species were not important to elk in the Minam unit. Deer use of browse came late and was highly variable among samples collected. Of the 37 percent browse in the diet, ninebark and creambush rockspirea (ocean-spray) made up 26 and 9 percent, respectively. Elk and deer consumed 65 and 96 percent, respectively, of their early diets of ponderosa pine. During the late period, considerably less ponderosa pine (25 and 26 percent for elk and deer, respectively) ($P<0.01$) was consumed.

Heppner Unit

Bluebunch wheatgrass and elk sedge were consumed more ($P<0.05$ and P.0.10, respectively) by elk than by deer. Elk also consumed more Idaho fescue ($P<0.05$) than did deer. Elk consumed considerably more fescue ($P<0.01$) during the late season than the early season. A significant ($P<0.05$) species-season interaction existed. Sandberg bluegrass occurred more in deer diets than in elk diets ($P<0.05$). Elk used this species more early, whereas deer use occurred late ($P<0.01$).

Considerably more grasses ($P<0.01$) were found in elk diets both early and late than in deer diets. Grass consumption by both deer and elk was greater during the late period ($P<0.05$).

Deer in the Heppner unit consumed 66 and 45 percent of their early and late diets respectively, as browse. Elk consumed considerably less ($P<0.01$); but both species consumed slightly more browse ($P<0.10$) during the early period. Snowbrush ceanothus was the primary species consumed, but up to 8 percent Oregon grape was also consumed. Ponderosa pine was not a major constituent of the diets, although it was consumed by both species and during both periods.

Ukiah Unit

Neither bluebunch wheatgrass nor elk sedge were important in deer and elk diets. Idaho fescue, selected by elk over all other species, made up 73 and 56 percent of early and late elk diets, respectively. Sandberg bluegrass appeared slightly more ($P<0.10$) in deer diets, especially during the late period. A significant ($P<0.05$) species-season interaction was present. Elk diets contained more grasses ($P<0.01$).

Browse species were higher in deer diets than in elk diets ($P<0.05$); early and late deer diets, however, contained only 7 and 11 percent. Deer consumed 32 and 50 percent ponderosa pine in their early and late diets, respectively--considerably more than that consumed by elk ($P<0.01$).

DISCUSSION

Considering overall seasons and areas, elk consumed 60 percent grass; deer, considerably less--33 percent. This species-diet relationship fits the classic belief that deer do not consume much grass but browse more consistently (Gill 1976). In the Blue Mountains, however, only deer in the Heppner unit consumed much browse in their diet. With the exception of late use in the Minam unit, deer in all other units consumed less than 15 percent browse in their diets (table 4).

The foothills of the Blue Mountains are not considered browse-producing winter ranges. Unless snow cover decreases availability, grasses could apparently make up the entire diet of both deer and elk. It appears though that in most cases deer and, to a lesser extent, elk use ponderosa pine as a portion of their normal diet.

Diet Overlap

Similarity index values for study locations and sampling dates are shown in table 5. Elk and deer were found to be compatible on most winter ranges during both early and late periods. The Minam unit showed a similarity value of 0.67 for early use; however, this is a bias datum caused by unusual weather conditions during that sampling period. Ponderosa pine was the principal species influencing the high diet overlap figure.

Table 5--Similarity index values of deer and elk diets by area and season

Study area	Early	Late	Mean
Walla Walla	0.71	0.42	0.57
Umatilla	.16	.81	.49
Minam	.67	.50	.59
Heppner	.42	.15	.29
Ukiah	.27	.25	.26

Dietary overlap also occurred on the Umatilla unit during the late sampling. Elk and deer diets were similar for amounts of Idaho fescue and ponderosa pine (table 4). Both animal species were eating new growth Idaho fescue at this period. Management of this particular winter range should be geared to Idaho fescue as it is the principal forage species consumed by elk and deer in the spring. Grasses were important early to both elk and deer on the Walla Walla unit. Care should be taken to leave areas with sufficient residual grasses available after cattle have grazed on this summer range.

Plant Values

Bluebunch wheatgrass, common in both elk and deer diets, was highly important in the Walla Walla unit. With one exception, both elk and deer always consumed more wheatgrass during late season than early season. The late sampling occurred after new forage growth was available in all units. Bluebunch wheatgrass was important as green forage. Deer on the Walla Walla unit were an exception. They consumed 29 percent bluebunch wheatgrass in their diets during the early period.

Elk sedge was also found in most diet samples, but never in consistently large amounts. In deer diets, sedge never exceeded 5 percent of the intake. This species is found in association with timbered areas which are primarily on the north-facing slopes of the winter range. Late season snow cover is more persistent here, and initiation of spring growth is later. Sedge, as well as other species found in association with the north slopes, was a minor diet component because of lower availability in late season.

Idaho fescue was the most important grass in both elk and deer diets over all areas. In all areas and seasons, elk averaged 33 percent fescue in the diet; deer, 8 percent. Deer on the Umatilla and Walla Walla units, however, consumed 44 and 42 percent, respectively, of Idaho fescue in their late diets.

Sandberg bluegrass was important on some units as a component of deer diet but was only important to elk in the early period on the Walla Walla unit and to a lesser extent on the Heppner unit. Deer have been shown to prefer Sandberg bluegrass in the spring even when other species are readily available (Vavra and Sneva 1979).

Ponderosa pine constitued 39 percent of the deer diet but only 19 percent of the elk diet over all areas and seasons. The high percentages recorded for both elk and deer in the Minam and Umatilla units for the early sampling are a reflection of sampling date. An unidentified conifer made up over two-thirds of early elk diets on the Umatilla unit. Samples were collected in the other units 1 week before the Umatilla and Minam units. A severe winter storm passed through northeastern Oregon at the time of sampling in the Umatilla and Minam units. Snow depth was in excess of 1 foot and temperatures were near 0°F. Little forage was available and low temperatures caused animals to move less; ponderosa pine was available in quantity with a minimum of exposure to the weather and was therefore readily consumed.

High composition of conifers in the winter diet is not unusual for deer and is often encountered for elk. In northern Idaho and western Montana, DeNio (1938) reported 36 percent conifers in winter diets of deer and 13 percent in winter diets of elk; Morris and Schwartz (1957) found that diets of deer in January in western Montana contained 74 percent conifers; diets of elk, however, contained only trace amounts.

Winter Diet and Animal Behavior

Snow and cold weather cause a change in animal behavior and apparently an attendant shift in diet, reflecting availabiity of forage. When sampling was done during or after a storm period, consumption of conifers by both elk and deer increased, causing a lower intake primarily of grass. This was a result of lower foraging activity (energy conservation) when animals were inhabiting forested areas for thermal cover.

Based on observations of elk and deer after protracted storms, forage is first grazed on open windswept ridges and upper, south-facing slopes where it first becomes available. These habitats should be favored for winter use of elk and deer in planning strategies for allocating the forage resource among ungulates.

As pointed out earlier, elk have greater foraging ability than deer because of differences in physical characteristics related to size. They have a higher browsing reach, greater mobility to seek better forage areas--especially through deep snow--and greater strength to paw frozen or crusted snow to obtain low growing food plants.

Animal Interaction and Nutrition

The importance of grasses in the diet increased in the late sampling. Increased consumption occurred mainly because new growth was available at that time. Elk and deer consumed 77 and 46 percent grasses, respectively, in their late diets. The early samples revealed 43 and 20 percent grasses in diets of both elk and deer. Grass consumption by deer elsewhere is also usually highest during this late time of year (Dietz and Nagy 1976, Vavra and Sneva 1979.

Dietz and Nagy (1976) suggested that overconsumption of young grass in the spring may result in digestive problems that could prove fatal. Deer in this study in the spring still maintained a diet of 54 percent browse and pine to add bulk to the diet and thus prevented digestive upsets. Maintaining this balance of bulk to new growth would be more critical for deer because of their decreased ratio of rumen size to total body mass and their increased metabolic rate compared with that of elk (interpreted from Bell 1971). Dietz and Nagy (1976) also stated that, because of the relatively small rumino-reticular size in deer,consumption of vegetation high in water content would decrease dry matter volume in the rumen and prevent intake adequate for maintenance.

About relative body maintenance, Bell (1971) stated that smaller ruminants need more protein and energy per unit of body weight per day than large animals do. Smaller animals (deer) could therefore lose weight more rapidly than larger ones (elk) during stress periods on equal but submaintenance diets. The absolute maintenance requirement is higher for the large ruminant than for the small ruminant. Therefore, the larger ruminant must consume more food per unit of body weight, but the food can be of lower quality than the smaller ruminant requires.

Deer, with this apparent need for higher quality winter forage, tend to be more selective of high quality forage than elk are, as evidenced by a significantly greater intake of shrubs; about four times more shrubs occurred in diets of deer than of elk. Deer also made twice as much spring use of Sandberg bluegrass as did elk; bluegrass is the first species to break dormancy in the spring and undoubtedly contained the highest protein content of all species sampled during the late period.

If deer and elk have the same food supply, elk can negatively influence deer populations if there are enough elk to remove the highest quality vegetation available. Under this situation, deer could not assimilate enough food daily to meet requirements. If the food on a winter range was of high quality but low in quantity, however, deer would be favored. On most western winter ranges the former situation exists. Therefore, on areas of common elk and deer use where dietary overlap occurs, increases in the elk population could conceivably decrease the deer population. On the other hand, where overlap is low, probably greater animal biomass could be sustained under use by both elk and deer than where only one species was maintained.

Management of winter ranges, then, should insure the presence of high quality forage for deer and high quantity forage for elk. Populations of elk need to be monitored closely because of their potentially severe impact on deer populations on common-use winter ranges.

SUMMARY AND CONCLUSIONS

During early and late winter on five important winter-range areas in the Blue Mountains, a study of elk and deer diets revealed that competition for forage between these two species is not normally high. The study also showed that shrubs are not as important in elk and deer diets here as on other big-game ranges throughout the intermountain west.

Weather data showed the period of study (1973-74) to be somewhat colder, with more snow than normal for the previous 10-year period.

Overall, grass made up 60 percent of the winter diet of elk and 33 percent of the deer diet, whereas shrubs made up less than 5 percent and 25 percent of the elk and deer diets, respectively. Conifers and several minor food items made up the balance; forbs were not a significant contribution to the diet in winter.

Different plant species contributed varying amounts to elk and deer diets, depending on the particular winter range. For example, bluebunch wheatgrass was most important on one range, whereas elk sedge or Idaho fescue was most important on another. For deer, Sandberg bluegrass was important on three areas, Idaho fescue on two, and wheatgrass another. Of all plants, Idaho fescue made the greatest contribution to the diets of both animals. Ponderosa pine was a consistent dietary item; and during storm periods, it was used in large quantities, especially by deer.

Some plant species, such as bluebunch wheatgrass, were routinely used more heavily by elk early in the winter than late. Seasonal use by deer was more variable. Deer made substantial use of Sandberg bluegrass during late winter, mainly as a result of spring greenup. Elk, on the other hand, made highest use of Sandberg bluegrass in early winter on these same areas; this animal-season interaction for Sandberg bluegrass was significant.

Diet overlap between elk and deer, as determined by analysis, was not high except for late season grazing in one unit Early season competition appeared to be moderately high on another unit, but this was mainly a result of weather and high consumption of ponderosa pine which is a low-value forage in superabundant supply.

As expressed here, evaluation of winter diet should be interpreted in terms of animal behavior characteristics which often reflect weather patterns. Snow cover decreases the availability of forage from which animals can select. Together with extremely cold temperatures, deep snow can decrease animal mobility, further biasing preference. In terms of survival under adverse weather, elk have greater mobility and better foraging ability than deer do.

Nutritional aspects of these dual-use winter ranges again place deer at a disadvantage relative to elk because of the low quality of available forage. Deer need higher quality forage than elk do because of their relatively higher metabolism and smaller rumen size to body mass. Apparently because deer select more nutritious forage, such as shrubs and emerging bluegrass, they are able to survive nearly as well as elk when presented the same available forage under normal winter conditions.

Based on early and late winter diets selected by elk and deer throughout the Blue Mountains, there appears to be little cause for concern about forage competition. Because of the competitive advantages enumerated, however, elk populations should be closely managed on ranges where high diet overlap exists.

LITERATURE CITED

Bell, R. H. V.
1971. A grazing ecosystem in the Serengeti. Sci. Am. 225(1):86.

Buechner, Helmut K.
1952. Winter-range utilization by elk and mule deer in southeastern Washington. J. Range Manage. 5(2):76-80.

Buechner, Helmut K., and Carl V. Swanson.
1955. Increased natality resulting from lowered population density among elk in southeastern Washington. 20th North Am. Wildl. Conf. Trans., p. 560-564. Washington, D.C.

Capp, John C.
1968. Bighorn sheep, elk, mule deer range relationships. A review of literature. 75 p. Rocky Mt. Nat. Assoc., Estes Park, Colo., and Dep. Fish. and Wildl. Biol., Colo. State Univ., Fort Collins, Colo.

Case, George.
1938. The influence of elk on deer populations. Univ. Idaho Bull. 33, p.25-27. Moscow.

Cliff, Edward P.
1939. Relationship between elk and mule deer in the Blue Mountains of Oregon. 4th North Am. Wildl. Conf. Trans., p. 565-569.

Cowan, Ian McTaggart.
1947. Range competition between mule deer, bighorn sheep, and elk in Jasper Park, Alberta. 12th North Am. Wildl. Conf. Trans., p. 223-227. Washington, D.C.

Daubenmire, R.
1970. Steppe vegetation of Washington. Wash. Agric. Exp. Stn. Tech. Bull. 62, 131 p. Pullman.

Daubenmire, R. F., and Jean B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Bull. 60, 104 p. Pullman.

DeNio, R. M.
1938. Elk and deer foods and feeding habits. In 3d North Am. Wildl. Conf. Trans., p. 421-427. Washington, D.C.

Dietz, D. R., and J. G. Nagy.
1976. Mule deer nutrition and plant utilization. In Mule deer decline in the West: A symposium, p. 71-78. Gar W. Workman and Jessop B. Low, eds. Utah State Univ., Logan.

Edgerton, Paul J., and Justin G. Smith.
1971. Seasonal forage use by deer and elk on the Starkey Experimental Forest and Range, Oregon. USDA For. Serv. Res. Pap. PNW-112, 12 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Garrison, G. A., J. M. Skovlin, C. E. Poulton, and A. H. Winward.
1976. Northwest plant names and symbols for ecosystem inventory and analysis. 4th ed. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gill, R. B.
1976. Mule deer management and myths and the mule deer population decline. In Mule deer decline in the West: A Symposium, p. 99-106. Gar. W. Workman and Jessop B. Low, Utah State Univ., Logan.

Griffiths, David.
1902. Forage conditions on the northern border of the Great Basin. Bur. Plant Ind. Bull. 15, 60 p.

Hansen, R. M., and L. D. Reid.
1975. Diet overlap of deer, elk, and cattle in southern Colorado. J. Range Manage. 28(1):43.

Kirsch, John B., and Kenneth R. Greer.
1968. Bibliography...Wapiti-American elk and European red deer. Mont. Fish and Game Dep. Spec. Rep. 2, 147 p. Helena.

Klein, David R.
1970. Food selection by North American deer and their response to over-utilization of preferred plant species. In Animal populations in relation to their food resources, p. 25-46. Adam Watson. Br. Ecol. Soc. Symp. 10, 477 p. Blackwell, Oxford.

Kufeld, Roland C.
1973. Foods eaten by the Rocky Mountain elk. J. Range Manage. 26(2):106-113.

Kufeld, Roland C., O. C. Wallmo, and Charles Feddema.
1973. Foods of the Rocky Mountain mule deer. USDA For. Serv. Res. Pap. RM-111, 31 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Miller, Richard Frank.
1974. Spring, summer and fall use by cattle and big game on foothill rangelands. M.S. thesis. Oreg. State Univ., Corvallis. 126 p.

Morris, Melvin S., and John E. Schwartz.
1957. Mule deer and elk food habits on the national bison range. J. Wildl. Manage. 27(2):189-193.

Oosting, H. J.
1956. The study of plant communities. 2d ed. 440 p. W. H. Freeman and Co., San Francisco.

Pickford, G. D., and Elbert H. Reid.
1943. Competition of elk and domestic livestock for summer range forage. J. Wildl. Manage. 7(3):328-332.

Robinette, W. L., N. V. Handcock, and D. A. Jones.
1977. The Oak Creek mule deer herd in Utah. Utah Div. Wildl. Resour., Publ. 77-15, 148 p.

Skovlin, Jon M.
1967. Fluctuations in forage quality on summer range in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-44, 20 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Skovlin, Jon M., Robert W. Harris, Gerald S. Strickler, and George A. Garrison.
1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 1531, 40 p. Washington, D.C.

Sparks, D. R., and J. C. Malechek.
1968. Estimating percentage dry weight in diets using a microscopic technique. J. Range Manage. 21(4):264-265.

Vavra, M., and F. Sneva.
1979. Seasonal diets of five ungulates grazing the cold desert biome. Proc. 1st Int. Grassl. Congr.

Ward, Lorin A.
1970. Stomach content and fecal analysis: Methods of forage identification. In Range and wildlife habitat evaluation: A research symposium, p. 146-158. U.S. Dep. Agric. Misc. Publ. 1147. Washington, D.C.

APPENDIX

Scientific and Common Names of Plant Species Mentioned[1]

Grasses:

Bearded bluebunch wheatgrass	*Agropyron spicatum*
Cheatgrass	*Bromus tectorum*
Idaho fescue	*Festuca idahoensis*
Letterman needlegrass	*Stipa lettermanii*
Mountain bromegrass	*Bromus carinatus*
Onespike danthonia	*Danthonia unispicata*
Pinegrass	*Calamagrostis rubescens*
Prairie junegrass	*Koeleria cristata*
Sandberg bluegrass	*Poa sandbergii*
Western fescue	*Festuca occidentalis*
Western needlegrass	*Stipa occidentalis*

Grasslike Plants:

Elk sedge	*Carex geyeri*
Northwestern sedge	*Carex concinnoides*
Ross sedge	*Carex rossii*

Forbs:

Balsamroot	*Balsamorhiza* sp.
Erigeron (fleabane)	*Erigeron* sp.
Hawkweed	*Hieracium* sp.
Heartleaf arnica	*Arnica cordifolia*
Lomatium (biscuitroot)	*Lomatium* sp.
Lupine	*Lupinus* sp.
Onion	*Allium* sp.
Rose pussytoes	*Antennaria rosea*
Rush pussytoes	*Antennaria luzuloides*
Stoneseed	*Lithospermum ruderale*
Strawberry	*Fragaria* sp.
Western yarrow	*Achillea millifolium lanulosa*

Shrubs:

Buckwheat (Wyeth eriogonum)	*Eriogonum heracleoides*[2]
Chokecherry	*Prunus virginiana*[3]
Creambush rockspirea (ocean-spray)	*Holodiscus discolor*
Ninebark	*Physocarpus malvaceus*
Oregon grape	*Berberis repens*
Rabbitbrush	*Chrysothamnus* sp.
Rose	*Rosa*
Sagebrush	*Artemisia* sp.
Shiny leaf spirea	*Spiraea lucida*
Snowberry	*Symphoricarpos albus*
Snowbrush ceanothus	*Ceanothus velutinus*

Trees:

Douglas-fir	*Pseudotsuga menziesii*
Ponderosa pine	*Pinus ponderosa*
Western juniper	*Juniperus occidentalis*

---

[1] Nomenclature follows that of Garrison et al. (1976).

[2] Locally considered a half shrub.

[3] Considered a tree in most areas.

GPO 989-175

Skovlin, Jon, and Martin Vavra.
1979. Winter diets of elk and deer in the Blue Mountains, Oregon. USDA For. Serv. Res. Pap. PNW-260, 21 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

From an analysis of fecal pellets, diets of elk and deer were compared during early and late winter of 1973-74 to determine the level of competition. Forage competition between elk and deer was not great even though winter conditions were harsher than normal on the five dual-use winter ranges studied. Shrubs were not as important here as in other winter range areas of the West. Idaho fescue was the single most important item in their diets.

KEYWORDS: Food habits (wildlife), range management, cervidae, Blue Mountains (Oregon), forage management.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
809 N.E. 6th Ave.
Portland, Oregon 97232

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.